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CLAY

BY

PAUL M. TYLER

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By Paul M. Tyler 2/

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2 - Assistant to chief, Economics Branch, U. S. Bureau of Mines.

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FOREWORD

The technology of clay and the manufacture of ceramic products therefrom, and also the clay resources of most of the individual States, is already covered by a voluminous literature. The present resume touches these matters only briefly; its purpose is essentially to bring together in small compass certain of the elementary factors affecting the potential commercial value of a clay deposit. In its preparation the author gratefully acknowledges the work of Jefferson Middleton of the Bureau of Mines who for many years has prepared the annual chapters on clay for Mineral Resources of the United States. For careful review and constructive criticism of the manuscript, the author is indebted to Hewitt Wilson.

GENERAL DESCRIPTION

The term "clay" includes a great variety of substances that may differ widely in chemical, mineralogical, and physical properties. No two clays are exactly alike. All of them, however, have the prominent characteristic of becoming more or less plastic when wet. Nearly all of the useful clays can be molded into articles, will hold their shape while being dried, and can be converted into a hard rock-like substance by heat. Clay may, and in fact usually does, consist of a number of minerals, among the commonest of which are kaolinite, quartz, feldspar, iron oxides, mica, bauxite, calcite, and manganese oxides. Organic matter is often present. Pure kaolinite, which has the formula $Al_2O_3 \cdot 2SiO_2 \cdot 2H_2O$, is ordinarily considered to be the parent "clay substance," but most clays contain other hydrated mixtures of alumina and silica (alumino-silici acids) along with indefinite amounts of sand and other nonessential minerals.[3] Even this so-called inert matter affects the plasticity, drying shrinkage, ease of drying, and final density, and at high temperatures may react chemically with the clay substance.

The names of many varieties of clay are derived from their principal uses which, in turn, are determined by their physical properties or their behavior in burning.

USES AND PRODUCTS

The different kinds of clay have so many uses that it is probably impossible to list them all, but the following rough classification will serve to point out the great variety of products that contain clay.

Structural Products.- Common brick; paving brick; face brick; sewer pipe drain tile; hollow block; terra cotta; conduits; roofing tile; flue lining and chimney pipe; floor and terrace tile; wall and fireplace tile; brick dust and

3 - Clay substance is also regarded as that part of clay which is soluble by digestion in hot sulphuric acid in the (so-called) rational analysis.

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crushed brick; calcined clay (e.g. railroad ballast), and mosaic wall tiles.

Refractories.- Fire clay brick and special refractories.

Pottery, Etc.- Tableware; kitchenware; sanitary ware; stoneware; art or garden pottery; flower pots; ollas, and other porous ware; electrical insulators; porcelain specialties, and cast-iron enamelware.

Minor Uses[4].- Food adulterant; paint fillers; crayons; paper filling; cosmetics; modeling; water softening; taxidermy; fulling cloth; oil filtering; scouring soap; toilet and tooth powders; packing for horses' feet; insecticides; chemical apparatus; condensing worms; ink bottles; ultramarine manufacture; emery wheels; playing marbles; battery cups; pins, stilts and spurs for potters' use; shuttle eyes and thread guides; smoking pipes; umbrella stands; pedestals; filter tubes; caster wheels; pumps; pump wheels; electrical procelain; foot rules; plaster; alum.

Use as Fillers.- The extremely finely divided nature of clays and their low cost make them of value as adulterants and as mineral fillers for rubber, linoleum, oilcloth, etc. Kaolin and certain other white clays are extensively employed in the manufacture of high-grade paper, window shades, and so on. Ochre, an iron-stained clay, is used mainly in linoleum; the best grades are also used in paint and wall coatings. The cheaper clays find similar uses in articles, such as heavy wrapping paper and cardboard, where the color is of minor importance. Bowles studied the matter of mineral fillers extensively in connection with the possible disposal of waste from slate manufacture, and it would seem that most of the uses for slate flour could be met by clay.[5] Clay competes with whiting in the manufacture of mechanical rubber goods, rubber tubing, friction and rubber tape, putty, window shades, etc. It is used in some paints, fertilizers, metal polishes, and abrasive soaps, for "rock-dusting" coal mines (as a safeguard against explosions), and for the manufacture of Portland cement. It appears to be adapted for use in road asphalt mixtures, plastic roofing, flooring, and, in short, for any purpose requiring an inert, extremely fine-grained material.

Weigel[6] has made a long series of experiments on the white clays or kaolins of Georgia and Alabama and has given in detail as far as possible the requirements of manufacturers and the methods employed for determining the availability of a given clay for certain purposes. With respect to the minor filler uses, however, he concluded (ibid, p. 33) that the desirable properties required in clay as specified by different industries and individual consumers, were quite conflicting. In general, whiteness and freedom from grit are the qualities most desired for such filler uses.

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4 - Largely from Ries, H., Clays, their Occurrence, Properties and Uses. 1st ed., John Wiley & Sons, New York, 1906, p. 217.

5 - Bowles, Oliver, The Technology of Slate. Bull. 218, Bureau of Mines, 1922, pp. 86-107.

6 - Weigal, W. M., Georgia and Alabama Clays as Fillers. Tech. Paper 343, Bureau of Mines, 1925, 35 pp.

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For the year 1927 the amount of domestic clays sold for filler purposes as reported by miners was as follows:

Consumption of clays for fillers, in short tons [1]

	Kaolin	Other clays	Total
Paper filler	192,307	1,201	193,508
Paper coating	3,510	- -	3,510
Rubber	27,428	3,147	30,575
Oilcloth or linoleum	14,511	- -	14,511
Paint filler or extender	12,084	1,250	13,334
Paint pigment	14	331	345
Asbestos products	440	1,943	2,383
Plaster and plaster products	6,224	[2]15,566	21,790
Cement	58,594	[2] 1,224	59,818
Kalsomine	3,959	- -	3,959
Crayons	500	- -	500
Total [3]	319,571	24,662	344,233

1/ Middleton, Jefferson, Clay in 1927. Mineral Resources of the United States, pt. 2, 1927.

2/ Principally fire clays.

3/ Exclusive of 10,618 tons of kaolin, 436,421 tons of fire clay and 403,045 tons of other clays (a total of 850,084 tons) listed as "unspecified" and sold for blast furnaces, building brick, conduits, copper ladles, cosmetics, enamelled brick, dobies, filtering or decolorizing oil, flue lining, flowerpots, hollow building tile, modeling, mortar colors, roofing tile, sewer pipe, smelters, soap, taxidermy, toy marbles, turpentine cups, water softener, etc.; also black-burning clays.

NATURE OF DEPOSITS

Clay is always of secondary origin. It results from the decomposition of other rocks, notably shales or impure limestones and igneous rocks containing feldspar. Old metamorphic rocks may weather again to clays. Sometimes the clay is found overlying the rock from which it was derived, and under these circumstances it is termed a "residual clay." Residual clays, many of them highly impure, are found in many parts of the United States but principally east of the Mississippi River and south of New York. Usually the deposits of residual clay constitute a broad mantle of considerable area, but occasionally, as when the clay results from the decomposition of a pegmatite, the deposit occurs in steeply inclined veins.

Sedimentary clays are stratified, and they usually bear no direct relation to the underlying rock. They consist of residual clays that have been transported by moving waters or of clays formed in the process of being transported. According to the nature of the water in which they have been deposited, sedimentary clays are variously described as marine, lacustrine (deposited in lakes or swamps), and stream. Clays transported by glacial action consist principally of boulder clay which may or may not have been stratified locally or worked over by streams. Wind-formed deposits or loess also sometimes consist of clay.

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After being deposited, clay beds frequently undergo various changes. They may be folded, up-tilted, or even faulted by movements of underlying rocks. Erosion likewise introduces various changes; sometimes, for example, a clay bed may be found only near the tops of various hills, the intervening portions of the bed having been removed, or again a bed originally covered by later sediments may be exposed and thus be workable only in the valleys or the lower hillside slopes.

PRELIMINARY EXAMINATION

It may be stated as a general rule that the economic value of a particular clay can be determined only by careful laboratory tests or by actual use in a commercial plant. The necessary tests, however, since they are fairly elaborate, may involve a considerable expenditure, and such expenditure may not appear to be worthwhile until more is learned with regard to the extent and degree of uniformity of the deposit. It is often desirable, therefore, to obtain a preliminary idea as to the possible usefulness of a clay, and actually a great deal can be learned by means of a few simple tests that can be conducted if necessary, in the field. Such preliminary tests are especially valuable from the standpoint of the examining engineer or prospective clay miner for the reason that the clay that one operator may reject as unsuitable for his ware or plant conditions may be acceptable elsewhere. The suggestions outlined below have been culled in large part from various State bulletins; many of them apparently were first described in the third report of the West Virginia Geological Survey.

Uniformity

The usual care should be observed in taking samples in order to make certain that they truly represent the bed or beds from which they are taken. Homogeneity is a matter of great importance if the clays are to be utilized industrially, and if the clay tends to vary in quality in different parts of the deposit that fact should be noted, as it would necessitate careful selection and mixing.

Slaking

A lump of the dry clay should be dropped in the water. Clays that slake or crumble down in a very few minutes are easily tempered; they can be rendered plastic without fine grinding. If several different clays are placed on a coarse screen and immersed, the time required for them to drop through the screen forms a rough measure of their relative slaking properties and possibly also of their relative bonding strength. According to a statement made by Hewitt Wilson in a private communication to the author:

> "The slaking of the remodeled dry bar (see clay tests of American Ceramic Society) is an indication of the bonding power, but not when the original structure is used. For example, a flint fire clay may resist slaking and be a poor bonding material; a sandy clay may fall apart at once; but the most plastic and best bonding clays, such as the ball clays, will resist for a greater time."

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Plasticity

The moist clay can be worked with the fingers to determine whether it can be molded into a definite shape and whether it will retain its shape without cracking when dry.

Shrinkage

A rough brick can easily be made; and when this is dry, a good idea may be obtained of the percentage of shrinkage. If the brick cracks or crumbles or if it warps out of shape, the value of the clay is rather doubtful; but in order to make a fair test, the clay should be ground thoroughly, tempered with the proper amount of water, and dried slowly. It may be possible to use high-shrinkage clays, such as ball clay, in pottery, terra cotta, or fire-clay bodies but they can not be used alone.

Color

Fired color is often said to be the most important property. The color of a finished clay product is ordinarily due to iron. Particularly in a clay containing organic matter, this color may not be apparent in the raw clay. Red clays will usually burn red, but blue, gray, and even quite light-colored clays may also burn to red or to various buff or brown shades. A pure white clay will not burn red. Unless clays are reasonably pure, they are likely to be distinctly gray, cream, or otherwise colored when wet, even though to the untrained eye they may look perfectly white, when dry. A small lump of clay may be roasted in a gas stove, a gasoline torch, or blacksmith's forge, with free access of air (never in a smoky flame), and then cooled. If it turns red or brown, the percentage of iron is high, probably more than 4 per cent. Unless carefully conducted, this test may not be conclusive, for the reason that with some clays a full firing temperature must be reached before the final color will be developed.

Fineness

Sand may be detected by grit against the teeth, and the percentage of sand present may be roughly estimated by this simple test. By repeated stirring and decantation in a tin cup or glass beaker, the clay can be floated off in suspension, leaving the sand and grit. Fineness of grain may have an effect upon fusibility and in filler clays is of much importance.

Soluble Salts

White coatings or efflorescence may be noted on the outcrop, especially where the clay is partly protected from the weather, as in a steep bank. By tasting the clay, bitter salts such as alum or epsom salts may be detected. The presence of soluble salts is apt to cause white wash coats on finished ware.

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Lime

High percentages of lime may ruin a clay. A few drops of strong hydrochloric acid will cause effervescence or bubbling if carbonates of lime or dolomite are present. Gravel and small fragments of rock, if present in any quantity, should also be tested in this way. If they consist of limestone they ordinarily should be removed; otherwise they often may be left in the clay and crushed to a smaller size.

Nodules and Concretions

Iron, manganese, and lime all form concretionary masses in highly weathered clays, not uncommonly following lines of stratification. Lumps of pyrite or nodules of chert occur in many deposits. The possible presence of such foreign material should be investigated and one should note whether it can be readily eliminated in mining.

LABORATORY TESTS

The standards or tentative standards of the American Ceramic Society[7] have been followed in most of the State geologists' reports on clays. Chemical analysis gives but little information with regard to physical properties and when physical tests of clay bodies are not satisfactory the chemical analysis serves to indicate the nature of the trouble and the proper remedy therefor. According to Wilson:[8]

> "Chemical analysis provides its most effective usefulness, in the case of high-grade clays, in estimating the degree of purity of the white-burning, kaolin-like materials and the alumina-silica-flux ratio in the fire clays, but in the case of the red and brown-burning structural-ware clays, the impurities furnish the most important data. We can but guess the fired color, strength, shrinkage, porosity, and vitrification range from the analytical data and for these properties, must rely on practical firing tests."

The weight of the sample collected in the field is usually about 50 pounds. In the laboratory the entire sample is usually crushed and passed through rolls.[9] To the 20-mesh material sufficient water is then added to permit the mixture to be worked into a plastic condition. After thoroughly working (wedging) the plastic mass, it may be covered with wet sacking and seasoned for at least 24 hours; then it may be made up into test pieces. These

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7 - See report of the Committee on Standards, American Ceramic Society. Reprint from Yearbook, 1921-1922, Ohio State University, Columbus, Ohio. Also Jour. Am. Ceram. Soc., vol. 11, June, 1928, pp. 442-447.

8 - Wilson, Hewitt, Ceramics; Clay Technology. 1st ed., McGraw-Hill Book Co., Inc., New York, 1927, pp. 45-46.

9 - Ref. cited, footnote 7.

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are usually pressed into molds 1 1/8 inches (30 mm.) square and about 8 to 12 inches long. Full-length bars may be used for dry transverse strength tests, but test pieces for drying and firing data are made by cutting the bars into shorter (1 7/8-inch) lengths. After being thoroughly air-dried in the laboratory the test pieces are heated at a higher temperature for a few hours before being placed in an oven and dried at 100°C. to constant weight. They are then kept in a desiccator.

The properties which are investigated in the laboratory are:[10]

I. General Character: Color, structure, fineness of grain, visible objectionable impurities, carbonates (acid test).

II. Working Properties: Ease of grinding, grade of plasticity, tendency to laminate, die troubles.

III. Drying Properties: Rapidity of drying, shrinkage, cracking and warping, tendency to scum.

IV. Burning Properties: Ease of oxidation; porosity at cones 07, 04, 02, 1, 3, 5, and 7; hardness at same heat treatments, shrinkage at same heat, color, behavior when overfired.

V. Refractoriness (for fire clays only): Fusion point - load test at high temperatures.

Some of these properties can not be described except in general terms. Plasticity, for example, depends in the first place upon producing a mixture having the proper working temper. This means that the clay must be mixed with enough water to develop its best properties. The degree of plasticity is reported as poor, fair, or excellent. The determination, however, is based upon the judgment and experience of the person who makes the test. A suitable clay, properly tempered, will be (1) fluid enough to take any required shape under reasonable pressure, (2) solid enough to resist change of form due to its own weight (i.e. not to slump), and (3) sticky enough to cohere and to heal itself after being pulled apart but not sticky enough to adhere to the hand or to meta

Slaking is determined by mixing equal parts of the dry clay and potter flint, and molding the mixture into 1-inch cubes which are dried first at room temperature and then at 100°C. The cube after cooling is submerged on a four-mesh screen, and a note is made of the time required for it to disintegrate sufficiently to fall through the screen. The stronger clays take a longer time to disintegrate so this test indicates bonding strength as well as possible difficulties to be encountered in practical operations.

10 - Staley, Homer F., Practical Handling of Iowa Clays. Iowa State College of Agriculture and Mechanic Arts, Eng. Exp. Sta. Bull. 43, 1916, 48 pp.

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The Water of Plasticity is the amount required to make the clay plastic. Ordinarily a highly plastic clay will require more water than one of low plasticity, and a clay that requires a large amount of water is likely to check or crack on drying. It should be noted, however, that water of plasticity is of two kinds, namely (1) shrinkage water which is that driven off in drying during the shrinking period and (2) pore water which is removed by heat at 110°C. after shrinkage ceases.

Drying Shrinkage is undesirable because it represents a tendency to warp and crack. It may often be reduced by mixing with other clay, sand, etc. which frequently may be derived from different beds in the same deposit. The shrinkage of fire brick and terra cotta is ordinarily reduced by adding calcined clay or ground brick, (grog) and in making whiteware the high shrinkage of ball clay is offset by adding ground flint, etc. Extremely sticky clays are likely to show an excessive air shrinkage. If necessary they can be preheated or again they may be given some special drying treatment after the goods are molded. The market price of the product determines whether such additional operations will pay; usually they will not.

The temperatures to which common clay wares are burned are shown in the following table compiled from data contained in a private communication from Hewitt Wilson:

Temperatures to which common clay wares are burned

Product	Seger Cone No.	Degrees Fahrenheit (approximate)
Common brick.....	012 - 02	1634 - 2030
Buff face brick.....	02 - 9	2030 - 2390
Fireproofing.....	03 - 4	1994 - 2210
Terra cotta.....	02 - 8	2030 - 2354
White earthenware....	8 - 9	2354 - 2390
Fire brick.....	5 - 15	2246 - 2606
Porcelain.....	11 - 18	2462 - 2714
Sewer pipe.....	02 - 7	2030 - 2318

In addition to the proper firing temperature, it is often necessary to learn the range of vitrification.

PROCEDURE IN REPORTING TESTS

The following forms for reports of laboratory tests have been recommended by the Standards Committee of the American Ceramic Society:[11]

11 - Jour. Am. Ceramic Soc., vol. 11, June, 1928, pp. 487-488.

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Chemical Analysis

(Form for clay, feldspar, and flint)

Identifying name or number_____.
Analysis based on material dried at 105°C:
Ignition loss____%.
SiO_2 (silica)____%.
Al_2O_3 (alumina)____%.
Fe_2O_3 (ferric oxide)____%.
TiO_2 (titania)____%.
P_2O_5 (phos. oxide)____%.
CaO (lime)____%.
MgO (magnesia)____%.
K_2O (potassium oxide)____%.
Na_2O (sodium oxide)____%.

General Clay Test

(Modified from Form of U. S. Bureau of Mines Station, Seattle, Wash.)

Identifying name or number_____.
Type of clay_____. Geological location_____.
Sampled by_____. Geographic location_____.

Original Properties

Dry color_____. Hardness_____.
Visible impurities_____.
Rate of slaking_____.
Mechanical analysis: Notes:

Plastic and Dry Properties

Wet color_____. General plasticity_____.
Temperature and time of drying:
Shrinkage water____%. Pore water____%.
Water of plasticity____%. Rate of slaking after drying:
Dry volume shrinkage (of dry volume)____%.
Measured linear shrinkage (of dry length)____%.
Dry transverse strength (lbs. per sq. in.)_____.
Drying behavior (cracking, warping, scumming):

Fired Properties

Cone and rate of firing_____.
Color_____. Hardness_____.
Volume shrinkage (of dry volume)____%.
Linear total shrinkage (of dry length)____%.
Per cent absorption____%.
Apparent porosity____%.
Transverse strength (lbs. per sq. in.)_____.
Firing behavior (cracking, warping, scumming):
Pyrometric cone equivalent_____.
Best firing range_____.

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Test of Refractory Clay

Received from_____. Date_____.
Identification_____. Type of clay_____.
P.C.E. (A.S.T.M. Serial Designation C24-20)_____.
Working properties_____.
Water of plasticity_____.
Drying shrinkage (by volume)_____%.
Drying behavior:

Draw Trial Data

Temperature	Cone	Per cent porosity	Volume change	Color
1000°C.				
1100				
1200				
1250				
1300				
1350				
1400				
1450				
1500				
1550				

Transverse Strength

Firing Temperature	Pounds per square inch (average of determination)
Green 1/	
1000°C.	
1200	
1300	
1400	
1500	

1/ Dried to 110°C.

CLASSIFICATION OF CLAYS

The laboratory tests of clays provide information sufficient to place the sample of clay in its proper place in a classification proposed by Parmelee[12] which may be re-arranged as follows:

12 - Parmelee, C. Ward, and Schroyer, C. R., Further Investigations of Illinois Fire Clays. Ill. Geol. Survey Bull. 38, 1922, pp. 278-9.

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I. Clays burning white or cream colored, not calcareous.

A. Open-burning clays (i.e. still distinctly porous) at cone 15 (2,606° F.).
Uses: If of good color or of good strength is used for pottery. If of good or high degree of refractoriness, used for various refractories; if also of good color, used for special refractories, e.g. pots for melting optical glass.

1. Low strength. Type: Residual kaolins of North Carolina.
2. Medium and high strength. Type: Secondary kaolins of Florida and Georgia.

B. Dense burning (i.e. become nearly or completely non-porous) between cones 10 and 15 (2,426 and 2,606° F.). Medium to high strength, medium shrinkage.

a. Nonrefractory clays:

3. Good color. Uses: Pottery, including certain whiteware, porcelains, stoneware.
4. Poor color. Uses: Stoneware, terra cotta, abrasive wheels, zinc retorts, face brick, saggers.

b. Refractory clays:

5. Good color. Uses: Refractories, especially for glass if they do not overburn seriously for 5 cones (180° F.) higher.
Also uses stated in 3.

C. Dense burning between cones 5 and 10 (2,246 to 2,426° F.) and do not overburn seriously at 5 cones (about 180° F.) higher than the temperature at which minimum porosity is reached.

a. Nonrefractory clays, medium to high strength, medium shrinkage:

6. Good color; usually reach minimum porosity between cones 5 and 8 (2,246 to 2,354° F.). Type: Ball clays. Uses: Pottery, whiteware, porcelain, and stoneware.
7. Poor color. Uses: Stoneware, terra cotta, abrasive wheels, zinc retorts, face brick, saggers.

b. Refractory clays:

8. Dense burning at cone 5 (2,246° F.); do not seriously overburn for 12 cones (about 432° F.) higher; highly refractory; softening point at cone 31 (3,182° F.) or higher; bonding strength minimum 325 pounds per square inch.
Use: Graphite crucibles for melting brass.

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9. Dense burning at cone 8 (2,354° F.) not over firing at cones 13 or 14 (2,550°F.). Strength and softening point as in 8.
Use: Steel crucibles.
10. Dense burning at cone 8 (2,354° F.) not over firing at cone 15 (2,606° F.). Binding strength, 250 pounds per square inch or higher. Softening point, cone 29 or higher. Use: Glass pots.

II. Buff burning clay.
A. Refractory clays.
a. Open burning (5 per cent porosity or more) at cone 15 (2,606° F.) or above. Indurated. Non-plastic or slightly plastic (unless weathered).
Type: Flint clays.
11. Alumina 40 per cent or less. Use: Refractories.
12. High alumina (over 40 per cent). Type: Diaspore clays. Uses: Refractories, abrasives.
b. Open burning (5 per cent porosity or more) at cone 15 (2,606°F.) but plastic.
13. Silica 65 per cent or less. Uses: Fire brick and other refractories, terra cotta, sanitary ware, glazed and enamelled brick.
14. High silica (over 65 per cent). Type: Many New Jersey fire clays. Uses: Fire brick and other refractories.
c. Dense burning (porosity under 5 per cent) between cones 10 and 15 (2,426 to 2,606° F.)
15. Medium to high strength, not overburning for 5 cones (about 180° F.) higher than point of minimum porosity. Uses: Glass pots, fire brick, saggers, and other refractories; architectural terra cotta, sanitary ware, enamelled and face brick.
d. Dense burning (porosity under 5 per cent) at cone 10 (2,426° F.) or lower.
16. See 8) Uses: Zinc retorts, fire brick, saggers
17. See 9) and miscellaneous refractories, ar-
18. See 10) chitectural terra cotta, sanitary ware, enameled and face bricks.

B. Nonrefractory clays.
a. Open burning (5 per cent porosity or more) at cones lower than 10 (2,426° F.).
19. High or medium strength. Uses: Architectural terra cotta, stoneware, yellow ware, face brick, sanitary ware.
20. Low strength. Use: Brick.

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b. Dense burning (porosity under 5 per cent) at cones lower than 10 (2,426° F.).
21. High or medium strength. Uses: Architectural terra cotta, stoneware, abrasive wheels, sanitary ware, face brick, paving brick.

III. Clays burning red, brown, or other dark colors.
A. Open burning (do not attain low porosity at any temperature short of actual fusion).
22. Medium or high strength. Uses: Brick, drain tile, hollow blocks, flower pots, pencil clays, ballast.
23. Low strength. Use: Brick.
B. Dense burning clays.
a. Having a long vitrification range (5 cones or about 180° F.)
24. High or medium strength. Uses: Conduits, sewer pipe, paving brick, floor tiles or quarries, electrical porcelain, cooking ware, silo block, art ware, face brick, architectural terra cotta, roofing tile.
25. Low strength. Uses: As dust body in the manufacture of electrical porcelain, floor tile, building brick.
b. Having a short vitrification range:
26. High or medium strength. Uses: Building brick, face brick, hollow block, flower pots.
c. Highly fusible, forming a glass at about cone 5 (2,246° F.).
27. Slip clays.

IV. Clays burning light gray or light cream.
28. Containing calcium or magnesium carbonate or both. Never attain low porosity. Very short heat range. Use: Common brick.

A much simpler classification but one which likewise depends upon the color and temperature-resisting qualities of the fired product is that proposed by Mellor:[13]

Nomenclature of Clays and Shales

A. Refractory (soften above 1,500° C.).
(1) Burn white or cream color, e.g., some pipe clays, china clays.
(2) Burn gray, buff, or red.

13 - Mellor, J. W., Clay and Pottery Industries. C. Griffin & Co., Ltd., London, 1914, p. 195.

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(a) Soften above 1,750° C., e.g., fire clays.
(b) Soften between 1,650 to 1,750° C., e.g., medium-grade fire clays.

B. Nonrefractory (soften below 1,500° C.)
(1) Noncalcareous.
(a) Burn cream or white color, e.g., ball clays and pottery clays.
(b) Burn buff or red (oxidizing), e.g., brick and terra-cotta clays.
(2) Calcareous (burn pale cream, buff pink, and red, e.g., marls, gault clays, etc.

VARIETIES OF CLAY

The principal types of clays have been named according to their leading uses. Since one variety of clay may be suitable for several purposes it may go by two or more names. On the other hand, the same name may be applied to widely different clays.

Nomenclature of this sort is obviously unsatisfactory, but until the physical and chemical characteristics of clays are better understood it will continue to be employed. In the following brief descriptions the effort is made to describe the characteristics of some of the leading types of clay that are commonly used for certain purposes and that are accordingly sought by manufacturers for such purposes. It should be kept in mind, however, that for many uses the peculiar properties inherent in the clays employed can not be defined closely. The clay-products industry is still conducted largely on an empirical basis, and the proper clay can often be found only by the costly processes of trial and error.

China clay is a commercial name for kaolin. Proposals have been made to call the crude material kaolin and that prepared for market china clay. Kaolin, since it rarely occurs naturally in deposits of sufficient purity, is usually obtained by washing out more or less accompanying sand, mica, and other impurities. It burns white, is highly refractory but not particularly plastic, and is the chief constituent of chinaware and porcelain. A distinction is often made between residual kaolins and secondary or transported kaolins. The latter are usually stronger but have higher shrinkage and the color may not be so good. They are fine grained and more plastic than residual kaolins but lack the bonding strength of ball clays. Stull and Bole[14] separate kaolins according to their structure and other properties into flint clays (resembling in many respects flint fire clays, hard clays, semihard clays, soft clays, and bauxitic clays (grading into bauxite). According to Ries[15]:

14 - Stull, R. T., and Bole, G. A., Beneficiation and Utilization of Georgia Clays. Bull. 252, Bureau of Mines, 1926, p. 10.
15 - Ries, H., Clays, their Occurrence, Properties and Uses. 3rd. ed., John Wiley & Sons, 1927, pp. 9-10.

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> "Kaolins are known to have been formed by weathering from a variety of rocks, as pegmatites (North Carolina), limestone (Pennsylvania), schist (Pennsylvania), shale (Virginia), feldspathic quartzite (Connecticut), granite (Cornwall, England), syenite (Arkansas), porphyry (Halle, Germany), etc."

Residual kaolins from North Carolina are used chiefly in the manufacture of whiteware, including chinaware and porcelain, floor tile, wall tile, and electrical porcelain and semiporcelain. The cream-colored sedimentary clays of South Carolina are employed as fillers in certain cheap textiles, cardboard, and paper; in the manufacture of colored hardware porcelain and of certain grades of electrical porcelain; in top-printing wall paper, and in cold water paints. These clays are also used as fillers in rubber goods and oilcloth and in the manufacture of certain kinds of patent roofing. The white clays found in Georgia and South Carolina are used for the same purposes and also for filling print, book, and magazine paper, and white cotton goods; for coating paper and cardboard (occasionally); for coating and top-printing wall paper in light shades; and for making white and colored kalsomine. The Florida clays are used in whiteware, floor and wall tile, and electrical porcelain but are not regarded as paper clays.

Paper clays are largely kaolins. The color in the natural dried condition is of special importance and the clays must be graded carefully accordingly A somewhat cheaper grade of clay can be used as filler than in the coating of calendered paper.

Ball clays are highly plastic strong clays that burn white or light cream. They occur as large masses that may roll around in shipping and become ball-shaped (hence, the name). These clays represent the finest of the pure clay substance that remains suspended for the longest time in lakes or swamps. Toughness is a characteristic property. They vitrify (become nonabsorbent) between cones 5 and 10 (2,246 to 2,426° F.). The drying shrinkage is ordinarily less than 10 per cent; modulus of rupture (cross-break test) varies from 200 to 500 pounds per square inch, averaging 350; the total shrinkage at cone 10 varies between 16 and 20 per cent. The water of plasticity varies between 27 and 43 per cent, averaging 32.6 per cent.[16] Mixed with china clay, ball clays give the body sufficient plasticity and bonding power. English ball clay, which vitrifies at lower temperatures than the domestic type was formerly used almost exclusively in this country, but considerable quantities of ball clay are now obtained in the western sections of Tennessee and Kentucky and smaller amounts are dug in New Jersey. Ball clays are used chiefly in white earthenware and porcelain but are also employed in floor and wall tile, electrical porcelain, certain glass refractories, and graphite crucibles.

Slip clays are fine grained and since they contain a high percentage of fluxes melt to a greenish or brown glass at low temperatures (preferably below 2,246° F. or cone 5). They should be free from lumps or concretions and have

16 - The figures in this paragraph are taken from Parmelee, C. W., and Schroyer, C. R., Further Investigations of Illinois Fire Clays. III. Geol. Survey Bull. 38, 1922, pp. 272-417.

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little drying shrinkage. Natural clays are usually preferred to artificial mixtures. Slip clays may be used for covering articles made of an inferior clay in order to improve the appearance. The slip clay is mixed with water to a creamy consistency forming what is known as a "slip" or slurry and is applied to the ware by dipping or spraying. It must be fine enough to remain suspended in water indefinitely. The use of slip clays for glazing stoneware is decreasing, as they are being displaced by an artificial white glaze. They are now principally employed as binder in the manufacture of artificial abrasives.

Fire clays are clays that withstand high temperatures and usually are not fusible below about 3,000° F. (cone 27 or 28). The term is used loosely, however, and almost all plastic clays found below coal seams whether or not they are refractory are likely to be called fire clay. Even true fire clays vary widely in all their properties. In an effort to bring order out of this chaos, the American Society for Testing Materials (Standard C 27-20) distinguishes: (1) High heat duty fire brick (divided according to composition into clay fire brick and siliceous-clay fire brick, of which the former has a higher pyrometric cone equivalent); (2) intermediate heat duty brick (cone 28); (3) moderate heat duty brick (cone 26); and (4) low heat duty brick (cone 19).

The main use for fire clays is for the manufacture of the different shapes of fire brick, but they are also used either alone or mixed with other clays in refractory cements, gas or zinc retorts, furnace or locomotive linings, crucibles, coke oven brick, saggers, and other refractory products, and in addition considerable quantities are used in the production of floor tiles and sanitary ware, stoneware, terra cotta, conduits, pressed and paving bricks, Portland cement, plaster, etc. Fire clays may be residual, but more often the commercial deposits are of sedimentary origin. The most important domestic sources are formations of Carboniferous age in Ohio, Pennsylvania, Kentucy, Indiana, Illinois, Maryland, West Virginia, and Missouri, but fire clays are found also in Cretaceous and Tertiary beds in various parts of the country.

Flint fire clays receive their name because of their flint-like structure and conchoidal fracture. They are not high in silica, in fact they sometimes contain more alumina than does kaolin, possibly because of the presence of diaspore (Missouri), gibbsite (Kentucky), or pholerite. There are both plastic fire clays and flint clays. The flint clays have little plasticity but are typically highly refractory. Usually they are bonded with plastic fire clays, but their own plasticity may often be improved by grinding in water. Like ball clays they have a high fire shrinkage and tend to crack.

Nodular fire clay (sometimes called "burley" or "burley flint clay") consists of aluminous (diaspore) or ferruginous nodules imbedded in fire clay.

Refractory bond clays are refractory clays with strong bonding power. They are of value for glass refractories, graphite crucibles, and (to a less extent) for bonding abrasive wheels. The famous Klingenberg and Gross Almerode clays, formerly imported very extensively from Germany, are of this type. The domestic supply now comes chiefly from northwestern Mississippi; western

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Tennessee and Kentucky; southern Illinois; near St. Louis, Mo., and Portsmouth, Ohio; and in small amounts from Alabama, New Jersey, and Maryland.

Stoneware clays are fairly refractory - often as refractory as those used in fire brick - but at the same time they must become dense at a relatively low burning temperature. Plasticity and toughness, low firing range, and good bonding strength combined with low shrinkage are all necessary. These requirements are generally obtained only by mixtures of different clays in proper proportions. Three or four clays are employed in the mixtures used for chemical stoneware. According to Parmelee and Schroyer:[17]

Stoneware clays should burn to a cream or light tan color, attaining low porosity at 2,246 to 2,390° F. (between cones 5 and 9). They should not yield soluble salts, and concretions, pyrites, coaly particles and other impurities if present in appreciable amounts must ordinarily be removed by washing. Though the clays vary materially in character, the average properties are about as follows: Water of plasticity 18 to 37 per cent, average 35 per cent; drying shrinkage from 5 to 13 per cent, averaging 8 per cent; strength by cross-breaking test 125 to 400 pounds, averaging about 250 pounds per square inch; tensile strength 100 to 300 pounds, averaging 150 pounds per square inch; minimum porosity 5 to 10 per cent, and usually developed between cones 5 and 10; average burning shrinkage about 8 per cent. Stoneware clays are produced principally in Ohio and Illinois and are used not only for stoneware but also for yellow ware, art ware, earthenware, and even for terra cotta.

Chemical stoneware clays according to Schurecht[18] should have high bonding strength, small drying and burning shrinkages, and a rather wide range of vitrification. Crushed stoneware scrap is sometimes added to reduce shrinkage, and feldspar is added as flux (in Europe, since the color is not important cheaper fluxes such as phonolite, trachyte, porphyry, and retinite are used instead of feldspar). Corundum is added to increase the temperature resistance of the body. Various glazes may be used.

Sagger-clays are of several types. Saggers are containers in which delicate ware is placed in firing and serve as a protection from dirt and gases in the kiln. They need to be fairly refractory but resistance to high temperatures is of less importance than ability to withstand moderate temperatures ov and over again. Saggers are generally made from mixtures of two or more clays and grog. As a rule one clay is an open-burning clay, for refractoriness, and the other a good bond clay, for strength.

Architectural terra cotta clays are similar to stoneware clays. They are ordinarily of good quality. Most manufacturers use semi-fire clays or mixtures of such clays with less pure clay or shale. Good bonding properties are required, and low shrinkage and freedom from warping are desirable, althou

17 - See p. 285 of ref. cited in footnote 16, p. 16.
18 - Schurecht, H. G., The Properties of Some Stoneware Clays. Tech. Paper 233, Bureau of Mines, 1920, 35 pp.

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since the clays are usually mixed with grog (ground burned clay), the final shrinkage can be controlled by the manufacturer. Being rarely washed they should be reasonably free from impurities; even as much as three per cent silica coarser than 200-mesh has been considered objectionable, although many good bodies contain much higher percentages of sand. Soluble salts should be absent, though small quantities, of course, may be neutralized with barium chloride, or, more commonly, barium carbonate. Red-burning clays are in much less demand than those yielding light cream or buff shades, and the latter are likely to be more refractory. Since the final color is often applied as a glaze, the exact color of the body is not important. High tensile strength is not required in the product; some of the clays burn hard and others open and porous. The clay should slake readily, forming a workable mass without delay, and should be strong and plastic - without, however, becoming sticky or rubbery. A mixture of two or more clays is usually employed. At least one of these clays should burn to a porosity under 10 per cent at moderate temperatures (cones 1 to 6 or about 2,102 to 2,282° F.) and should not warp or crack in the drying process. Suitable clays are widely distributed, being found in beds of various age in New Jersey (Cretaceous), Pennsylvania, Indiana, Missouri (Carboniferous), and on the Pacific coast (Tertiary). Hewitt Wilson, in a private communication, states that in the Pacific Northwest, tertiary shales are largely used, sometimes mixed with Pleistocene clays.

Roofing-tile clays should possess good plasticity and strength when dry. The product must be flat, so that they must not warp or crack in drying or burning. Proper color after firing is important; most of the clays or shales are red burning. If unglazed they should fire to a hard dense body.

Sewer-pipe clays, according to Ries:[19] "should be sufficiently plastic to mold in the pipe press, dry and burn without cracking, have good transverse strength when dry, and show freedom from soluble salts, as well as from lumpy fusible impurities. The composition should be such as will permit the taking of a salt glaze (i.e. siliceous). The pipe may be fired at as low a temperature as 1,000° C. (1,832° F.), or usually appreciably higher."

The raw materials may be a red-burning vitrifiable shale or clay or a mixture of an impure clay with fire clay. A dark-colored product is generally preferred. In the Eastern and Central States sewer-pipe clays are obtained chiefly from Carboniferous formations and to a less extent from the Devonian; Cretaceous and Tertiary beds of the Coastal Plain are usually unsuitable, though in the Rocky Mountains and Black Hills some of the Cretaceous shales have good vitrifying qualities. Pleistocene clays are used only to mix with other materials. Triassic shales are used in North Carolina.

Common brick clays are mostly red-burning and are often low grade; even calcareous cream-burning material is used where better clays are not to be had. Almost any clay that will mold easily and burn hard at a fairly low temperature (usually below cone 1 or about 2,100° F.). More plastic clays are required for

19 - Ref. cited, p. 346, footnote 8, p. 7.

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stiff-mud than for soft-mud brick. Excessive drying or fire-shrinkage even may be reduced by mixing with other clays or sand (tempering). Common clays are found in every state. Those chiefly employed are of Pleistocene age and are found near the surface. Residual clays are utilized in several of the southern States. Shales are rarely made into common brick. Adobe is a silty clay, usually containing considerable lime, employed for making sun-dried brick. Loess is a common deposit of recent age in the Mississippi Valley, eastern Washington and northwestern Idaho, and is widely used for brickmaking; it may or may not be of Aeolian origin.

Face brick calls for higher-grade clays. They may be (1) red-burning, (2) white-burning, or (3) buff-burning. The demand for red-burning clays has fallen off, and as manganese and a few other artificial coloring agents are increasingly employed, the demand for buff-burning, refractory, or semirefractory brick has increased. The physical requirements of face brick clay are (1) uniform color in burning, (2) freedom from warping or splitting, (3) absence of soluble salts, and (4) sufficient hardness, and low absorption when burned at a low temperature. As face brick is usually burned quite hard, the clay should have a good range of vitrification; otherwise there would be a heavy loss in deformed brick.

Enameled brick are usually made from materials similar to those employed for buff face brick, but they are covered with an enamel of the desired color.

Fireproofing and hollow-brick clays vary according to the locality. Common red brick clays are used, sometimes with the addition of a little fire clay. Specifications for these products are given in Engineering News, vol. 47, p. 248. In general, clays used for fireproofing are similar to those used for common face brick and other structural wares. They need only to be a little stronger to flow through the die in thinner sections.

Paving brick mixtures are similar to those employed for sewer pipe. They should mold easily in a stiff-mud machine, be of satisfactory strength, and have a long-firing range. Toughness of the product is the principal requirement, and the composition and raw properties give little information as to this essential characteristic. Shales, low-grade fire clays, and vitrifiable plastic clays are all employed.

Fuller's earth is a clay that has a well-developed capacity for adsorbing basic colors and is suitable for bleaching and refining oil and other liquids. Most fuller's earths contain exceptionally high percentages of water, but chemical analysis is no criterion of their value, and even their physical appearance, color, and other properties may vary widely.

Bentonite is a peculiar clay vary similar in composition to certain kinds of fuller's earth. It is an alteration product of the weathering of the glassy particles of a volcanic ash or tuff. It appears to be highly colloidal

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and has a remarkable capacity for adsorbing water.[20]

"Colloidal clay", as stated by Oliver Bowles in a letter to the author, has several different meanings. Some American companies regard it as a synonym for bentonite. Other American companies and certain English firms apply it to a specially prepared product obtained by deflocculating a high-grade clay, settling out all coarse particles, and finally coagulating and collecting the material. Colloidal clay is used for the manufacture of antiphlogistine and similar medical preparations, for face creams and other toilet preparations, for special paints, and to replace carbon black in rubber manufacture.

Bauxite and high alumina clays: The alumina content of pure kaolin is 39.8 per cent, but certain clays contain higher proportions. Bauxite is not a silicate but a hydrate of aluminum and when pure is the ore of aluminum. It is employed for refractories and in the electric-furnace production of crystalline oxide of aluminum, which in turn is used both as a refractory and as an abrasive. The diaspores of east-central Missouri likewise are not clays, but nevertheless are now used extensively for making fire brick which have proved to be more refractory than those obtained from ordinary fire clays.

Shales are clays that have been compressed and possibly heated somewhat subsequent to deposition, making them more or less stony. They are not plastic but exposure to the weather tends to make them more clay-like, and continued grinding ordinarily restores their plasticity completely. They are used to a large extent in the manufacture of various ceramic articles, either replacing or supplementing true clays.

Bedded clays are soft clays which show definite stratification but which have not been hardened into shales. They may originate as alluvial clays, glacial-lake clays, etc.

Boulder clay, as the name implies, is clay containing variable proportions of stones, gravel, and sand. Occasionally such clays can be utilized after washing and screening or crushing.

Marls are clays containing considerable proportions of calcium carbonate (chalk).

Cement clays -- analysis important, although the range in ratio of silica and alumina is considerable. The composition desired will depend, of course, upon the nature of the cement rock or limestone with which they are to be mixed.

Polishing and abrasive clays are best exemplified, as a product, by Bath brick, which is made from lightly fired fine-grained siliceous clay found along the tidal flats of the Parrett River in England.

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20 - For further information on bentonite, see Davis, C. W., and Vacher, H. C., Bentonite; its Properties, Mining, Preparation and Utilization. Tech. Paper 438, Bureau of Mines, 1928, 52 pp.

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Loams are mixtures of clay and sand containing more or less vegetable matter. Strong loams are those that contain much sand. The only industrial usage of loams is in foundry work.

MINING METHODS

Clay is mined mostly in open pits. In the larger operations steam shovels are employed, although some of the better qualities of clay, since they are likely to occur in relatively thin or irregular beds, can only be worked by pick and shovel. Overburden may be stripped by steam shovel or hydraulicking at large operations or by means of plows and scrapers or even wheelbarrows at smaller properties or where the thickness of cover is small. Occasionally the stripped material can be used for tempering the clay itself, or the sand, gravel, and boulders can be removed by washing or screening and can be marketed for road construction or concrete purposes. Thick-bedded clays may be mined in one or two lifts. With an ordinary steam shovel there is no advantage in carrying a bank over 18 to 24 feet high, because the upper part can not be dug by the shovel but must be shot down. Machines of the shale-planer type are adapted to greater heights.

Under the peculiar conditions existing at one locality in Florida, dredges were first employed, but these have been replaced by pressure pipes, which stir up the bottom, and a suction pipe, which carries the slip to the washers. The country is flat and the ground-water level is close to the surface, so that ordinary open-cut methods would be unsuccessful. The clay carries sand and, after being dug by the dredge, is forced through a pipe to a series of three "sand traps" or classifiers. The suspended clay then passes through a series of troughs in which most of the remaining impurities settle out. The overflow from these troughs is conducted into settling vats and is finally filter-pressed. The cakes of damp clay from the filter-press are dried in sheds and then shipped. Except for the small amount lost in the "sand traps," practically all the clay is recovered; all the water, some of which necessarily carries more or less clay, is returned to the pit.[21]

Underground mining is occasionally resorted to although it is seldom successful if the clays are soft or require artificial support. The shaley clays associated with coal beds, however, are frequently mined through shafts and drifts. According to Ries,[22] underground methods are desirable only under certain conditions, namely:

1. In mining high-grade clays.
2. Where there is much overburden as compared with the thickness of the clay.

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21 - Bell, Olin G., A Preliminary Report on the Clays of Florida. Fla. Geol. Survey, 15th Ann. Rept., 1922-1923, p. 234.

22 - Ries, Heinrich, Clays, Their Occurrences, Properties and Uses. 3rd ed., John Wiley & Sons, New York, 1906, p. 212.

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3. Where there is a strong water-tight roof. Often it is necessary to leave about 1 foot of clay above and below to form a roof and a floor.

4. Where the workings are dry. The presence of water not only introduces pumping charges but also materially increases the difficulty and the danger of mining.

5. Where the output is small or where a large area can be opened up by several shafts or drifts.

In the southern Appalachian region kaolin used to be mined by a combination of open-pit and underground methods. Large circular shafts 14 to 20 feet in diameter were sunk in 4-foot lifts and lined with 4 by 6 by 30 inch wooden blocks, which were laced together and keyed in place. The joints were staggered as in laying brick. After reaching the bottom of the deposit, which was anywhere from 40 to 100 feet below the surface, drifts were dug radially outward from the shafts for such distance as appeared safe, usually about 10 feet, in every direction. The waste was not hoisted but was stowed back into the workings, and after the pillars between the drifts had been robbed, the whole area was filled with additional waste which was run in from the surface when required. Mining then proceeded upward on successive horizons until the surface or capping was reached.[23] Hydraulic mining has superseded the older methods. The large circular cribbed shafts are still sunk, but they are now used for sumps into which the surrounding clay is washed by hydraulic jets. The clay-sand-mica mixture is raised from the bottom of these shafts by bucket elevators and is discharged into troughs leading to the crushing plant.[24]

Mining Costs

In California[25] the total costs for open-pit work ordinarily range between 20 cents and $1.50 a ton. For mining alone the approximate figures are 10 to 20 cents a ton for scraper or power-shovel loading and 20 to 50 cents a ton for hand-loading (up to $1 if there is much hand-sorting). Tramming out of the pit or carriage to a nearby bin costs from 5 to 25 cents a ton, and incidental charges also vary between 5 and 25 cents a ton. Royalties, where paid, range usually from 10 to 25 cents a ton. Underground mining costs naturally average higher, but they must be kept down to $1 or less for mining, loading, and sorting. The determining factor in every case is price per ton f.o.b. cars, which is only $1 for certain cheap grades but ranges upward to $5.50 for rarer varieties.

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23 - Details of this and other methods employed in clay mining in the South are given by Watts, A. S., Mining and Treatment of Feldspar and Kaolin in Southern Appalachian Region. Bull. 53, Bureau of Mines, 1913, 170 pp.

24 - Stuckey, Jasper L., The Kaolins and Kaolin Production of North Carolina. Ceramic Age, Sept., 1928, p. 88.

25 - Dietrich, W. F., The Clay Resources and the Ceramic Industry of California. Bull. 99, Calif. State Mining Bureau, 1928, p. 21.

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PREPARATION OF CLAY

The preparation of a marketable product begins at the mine or pit. The impurities in clay characteristically run in streaks or beds and hence in mining need not be mixed with the clay itself. Except under unusual circumstances only the more expensive and better qualities of clay are worth beneficiating. Usuall a little hand-picking or screening represents all the expense that can be borne by the material. Only kaolin is washed extensively, although the better kinds of fire clays, glass pot, and ball clays, and, under exceptional circumstances, cheaper clays are also washed occasionally.

In any washing process the purpose is to get the clay itself into suspension and to separate it from the sand, small stones, or other foreign matter that may be present. This operation is facilitated by a method of mining, such as hydraulicking or dredging, that will break up the clay balls. Continued soaking under water in a pit softens certain clays satisfactorily. Many clays can be partly disintegrated by exposure to the weather and then the dried material may be crushed in rolls preparatory to mixing it with water. A log-washer or similar device, however, is ordinarily necessary. In one type of cla cleaner the material is mixed into a paste with water and then pressed against a perforated plate having holes about one-sixteenth inch in diameter. Another clay-washer is merely a tank equipped with a stirring device; the clay overflows from the tank in the form of a thick slip or slurry while the stones and other heavy matter remain at the bottom, whence they are periodically removed.

Details of washing methods applicable to high-grade clay have been described in bulletins of the Bureau of Mines.[26] Common practice is to blunge the clay thoroughly in a rectangular blunger 10 feet long 4 feet wide and 4 fee deep; this treatment produces a slip, which is led through narrow troughs in order to settle out the coarser sand. Fine sand and mica are removed in the "mica troughs." The slip is then passed through a 100-mesh or finer screen and run into thickening tanks, after which it is filter-pressed. The filter cakes, containing perhaps 25 per cent of water, are then dried (usually by exhaust steam or in open-air sheds) and finally crushed into small pieces by means of corrugated rolls. The preparation of a fluid slip with a minimum amount of water is favored by the addition of lime or other suitable alkaline substance. According to Bleininger:[27]

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26 - Watts, A. S., Mining and Treatment of Feldspar and Kaolin in the Southern Appalachian Region. Bull. 52, Bureau of Mines, 1913, 170 pp.
Stull, R. T., and Bole, G. A., Beneficiation and Utilization of Georgia Clay. Bull. 252, Bureau of Mines, 1926, 72 pp.
Sproat, I. E., Refining and Utilization of Georgia Kaolins. Bull. 128, Bureau of Mines, 1916, 59 pp.

27 - Bleininger, A. V., Use of Sodium Salts in Purification of Clays and in the Casting Process. Tech. Paper 51, Bureau of Standards, Sept. 25, 1915, p. 38.

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"The washing of kaolinitic clays may be decidedly improved as far as the quality of the product is concerned by adding to the water in the blunger a definite small amount of caustic soda or a mixture of caustic soda and sodium silicate. This treatment improves the color of most clays, enriches their content in clay substance, decreases the drying shrinkage, but tends to increase the burning shrinkage."

The Dorr classifier, especially the bowl classifier, has been introduced successfully for washing clay.

Drying is usually on steam pipe racks but later installations include rotary dryers, spray dryers, steam-heated drum dryers (in which the slip is spattered or sprayed onto a revolving drum), and car tunnel dryers.

SIZING

Many clays are broken up into extremely minute particles after thorough blunging but this is not true of all clays. Moreover, sand, mica, and numerous impurities that may be present are not decomposed by agitation with water, and often they are not completely broken up even by grinding with water in a ball or pebble mill. For use in fillers the grain ordinarily should be so fine that only a small fraction of 1 per cent would remain on a 325-mesh, the finest screen which is commonly available for testing. Most of the particles should be very much finer. In the manufacture of bricks, roofing tile, terra cotta, drain pipe, and coarse pottery, the material ordinarily has to pass only 24-mesh when prepared into slurry, but minus 50-mesh material is necessary for earthenware pottery, and for fine chinaware the material should at least pass 80-mesh. Large grains help the ware to resist temperature changes, but they are more likely to be supplied by adding grog or burnt clay.

The material separated from a clay deposit may be classified according to size as follows:

Clay: All grains under 0.01 and not settling in a current of water with a velocity of 0.18 millimeters per second (20 mm. head).

Silt: Grains 0.01 to 0.025 millimeters and not settling in a current of 0.7 millimeters per second.

Dust sand: Grains 0.025 to 0.04 millimeters and suspended a stream of 1.5 millimeters per second.

Fine sand: Grains 0.04 to 0.33 millimeters.

Coarse sand: Over 0.33 millimeters.

WEATHERING

The action of the weather on clay is often quite beneficial. The hardest shales can frequently be worked almost as easily as the softest plastic clays after they have been subjected for a season to freezing and thawing. Even

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a few hours' exposure to the air may be helpful. Some clays are loosened up in the bank and allowed to stand from 24 to 48 hours, as this tends to dry them so that they will absorb water much more rapidly. In northern States brick manufacturers have often found that time is saved and better brick are made if the clay can be mined in the fall and allowed to weather during the winter before being used.

The precise nature of many of the changes induced by weathering can only be surmised, as they have not been fully investigated. These changes are both chemical and physical. The effect of freezing, of course, is one of mechanical disintegration, and the natural loss or gain in moisture likewise is largely a physical effect, although the water also may both enter into chemical combinations with the clay substance and dissolve out soluble salts. Sunlight appears to favor oxidation and therefore has more or less influence. Certain clays show remarkable differences in character after even a few hours' exposure to the sun and air; others are scarcely affected. There are certain clays which actually become less plastic the longer they are exposed, but as a general rule weathering increases the plasticity of clays and yet at the same time improves their slaking qualities.

Weathering does not have much effect on the firing properties. In some cases it may even be hurtful, as it tends to change sulphides (if present) into sulphates and cause trouble from scumming. European customs favor weathering, but in the United States it is usual to do more mechanical preparation, if necessary, rather than undergo the extra handling and storage expense entailed by weathering.

SOURING OR AGEING[28]

Clay pastes are often kept moist and cool for a considerable time in order to distribute the water more uniformly and to improve the homogeneity and working properties. Ageing has a remarkable effect on plasticity, particularly in the case of weakly plastic, artificial pottery bodies containing a large amount of nonplastic material such as feldspar and flint. The aged body is much tougher and smoother, will flow more easily under the tool, and will give less cracking. The prolonged contact, moreover, brings about a better penetration of water into indurated grains of shale, fire clay, or clay balls.

To be effective, souring must take place in the presence of an ample quantity of water, and certain famous pottery manufacturers have aged their clays for several years in air-tight boxes. Since one of the effects of souring appears to be due to the decomposition of organic matter and the formation of dilute acids which coagulate the fine grains and thus increase plasticity, ageing may be hastened by the addition of gums, tannin compounds, or humus. Acid is sometimes added to the clay directly but, while this may improve the properties, it is not usually so satisfactory -- possibly because the acid is not thoroughly distributed through the mass. Acid, however, does neutralize the free alkali which prevents any improvement by souring; hence, the practice of adding old vinegar or wine which at one time was common among pottery manufacturers. Souring is usually conducted at atmospheric temperatures, but some

28 - Ageing is usually done by the manufacturer or clay products, whereas the other means of beneficiating the clay are considered as pertaining to the preliminary treatment and fall upon the producer or miner. In practice it is an unimportant process except in the higher types of pottery bodies.

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authorities recommend temperatures up to about 100° F. as being preferable to 60°, for example.

PLASTICITY

The relative ease with which a clay can be molded or made to flow through a die is the measure of its plasticity. Clay falls apart when placed in water, and its disintegration, ordinarily termed "slaking," is hastened by grinding or stirring. If the amount of water used represents 20 to 30 per cent of the weight of the clay, a plastic paste may be produced by proper mixing or pugging. If to this paste an equal amount of water is added, a slip or slurry should be produced. In general the softness of the plastic mass varies in proportion to the amount of water present.

The sundry phenomena of plasticity are not simple. This property is variously ascribed to (a) molecular attraction, (b) surface tension, and (c) colloidal conditions. The nature and relative proportion of sandy material present and various actions induced by the presence of bacteria or other organic matter may be contributory influences.

Many of the useful properties of clay are undoubtedly due to the content of colloidal substances which in paste are usually in the "gel" state and in slips are in the "sol" state. Like gelatine, silicic acid, and the hydrates of iron and aluminum, these colloidal substances in clay can undergo hydrolysis, osmosis, and adsorption. They shrink or swell in proportion to their loss or gain of water and change from the "gel" to the "sol" form, or vice versa, in the presence of positive or negative ions. According to Wilson:[29]

> "In plastic clay we are dealing with colloidal matter, combined with minute grains and surrounded by water films * * * *. The clay colloid is a reversible one. In neutral or alkaline solutions, the clay particles, between 0.1 micron and 1.0 millimicron in size, move independently of each other, cannot be seen under the ordinary microscope, and are in the sol or dispersed state. In acidic solutions, the sol flocculates, precipitates, or coagulates * * * * *. The change of state is easily effected with the proper amount of alkali or acid. Likewise, if the mechanical and adsorbed waters are removed by drying, the clay may be brought back to the colloidal solution again by the simple addition of water. If the temperature is raised beyond the dehydration temperature of the chemically combined water, however, an irreversible set gel condition develops, and the mass loses its ability to become plastic again save by processes similar to those by which the original parent igneous rock was transformed into plastic clay."

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29 - See pp. 61 and 64 of ref. cited in footnote 8, p. 7.

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Without going further into the intricacies of colloidal chemistry[30] it is convenient to consider the plasticity of clay as being due to films of viscous fluid matter surrounding inert solid particles, like linseed oil in putty. When the clay is dry the colloidal films shrink, and as they grow hard and horn-like they cease to lubricate the solid particles and the clay ceases to be plastic. On the other hand the addition of water, provided the drying has not been carried on at a temperature high enough to remove water that is chemically combined (e.g. firing), softens these films, rendering the clay plastic again, and when enough is added the clay is in suspension. In certain respects the behavior is similar to that which might be expected from particles of fine sand coated with glue.

There are sticky clays which adhere to any solid matter with which they come in contact, but they can be made less sticky and more plastic by partly drying them or by mixing them with sand or other inert matter.

The plasticity of a clay can be increased[31] (a) by suitably altering the proportion of water, (b) by better mixing so as thoroughly to incorporate the water into the plastic material, (c) by removing some of the nonplastic matter (usually making a slip and allowing the sand, etc. to settle out), (d) adding an acid or a substance which, like peat, cellulose extract, etc., will produce free acid or fermentation, (e) by adding colloidal substances such as colloidal silica, alumina, iron hydroxide, hot starch, dextrin, tannin, rubber, sumach, caramel, gelatin, gums, or glycogen, (f) by adding any flocculating or coagulating agent such as acids or "sols" of opposite sign, (b) by electrical treatment to reverse the electric charge of the material, (h) grinding or pugging with water, and (i) by ageing or souring.

MANUFACTURE OF CLAY PRODUCTS

The principal steps in the manufacture of articles from clay are:

(a) Preliminary treatment of raw material.
(b) Preparation of paste or slip of the proper consistency.
(c) Shaping articles.
(d) Drying.
(e) Burning or firing.

Mention has already been made of various methods for the preliminary treatment of clay. With regard to the many manufacturing processes for ceramic products it is not the purpose herein to go into much detail. A brief outline of the general nature of the principal operations will be given, however, for the purpose of indicating more definitely what properties are requisite in a

30 - "Colloidal chemistry is the chemistry of bubbles, drops, grains, filaments and films, because in each of these cases at least one dimension of the phase is very small." (Bancroft, W. D., Applied colloid chemistry, 1926, p. 183.

31 - Searle, A. B., The Chemistry and Physics of Clays. Ernest Benn, Ltd., London, 1924, pp. 272- .

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clay in order that it may be suitable for commercial uses. It should be recognized that in the case of such bulky products as brick and tile the methods of production must be cheap and efficient. Complicated procedures must be avoided and rarely can a clay be used that requires much preparation or careful handling. For higher-grade wares, quality is the determining factor, but since most of the pottery manufacturers demand that their raw material be delivered to them ready for use without further cleaning or grinding, any preparatory operations must ordinarily be performed by the miner.

Preparation of Clay Pastes

Since the consistency of a clay depends upon the amount of water it contains, means must be provided to mix the clay (and other ingredients, if any) with water to form a homogeneous mass of the requisite plasticity. In the production of high-grade earthenware and china a great deal of care is given to the preparation of clay paste. Usually a considerable amount of blending is also necessary, as few clays are suitable alone for producing high-grade ware. In addition to one or more clays, frequently quartz, feldspar, etc., are incorporated into the mix.

Spade mixing is a preliminary treatment in small operations and is the only treatment for making coke and tar mixtures of clay.

Pugging mixes the material with the proper amount of water. One type of pug mill is a horizontal trough having rotating blades; another is a cylindrical mill. The pug mills are used for some kinds of pottery and refractory brick, as well as for common brick, tile, terra cotta, and cheaper products; but although they produce a fairly good structure, they tend to introduce air bubbles.

Tempering is a name applied to any process by which a clay paste is made, but, especially in England, the term may be restricted to the use of an edge-runner mill or what is known in this country as a wet-pan pug mill. The wet pan is a circular bowl in which the material is ground, rinsed, and rubbed together by means of two or more heavy rotating rollers. It is used for screw pipe and various special bodies.

The dry pan is found in most clay-working plants, particularly where a soft shale or a hard, tough, dry clay has to be disintegrated. In general construction it resembles the wet pan, except that the latter, instead of being solid, is made up of removable, perforated plates through which the material falls as soon as it is ground fine enough.

Blunging is more of a stirring than a kneading operation and results in the production of a creamy liquid or slip. Ordinarily the clay and other materials are placed in a tank with water and agitated by a number of arms attached to a revolving shaft.

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Molding and Shaping

Articles are formed from clay mixed in various proportions with water. Bricks, for example, are molded as (1) very soft mud, (2) as stiff mud, or (3) almost dry. Pottery may be molded by hand or pressed into molds by hand or machine. It may also be turned on a wheel or again it may be (4) diluted with enough water to form a slip and then "cast" into plaster molds.

The soft-mud process is the oldest brickmaking process. It is adapted to more different kinds of clay than the other processes, and since the shaping can be done either by hand or by machine it is still widely used for common brick, face brick, and hand-pressed terra cotta and tile. Soft-mud articles are pressed into individual molds, and the excess clay is struck off by a steel scraper.

In the stiff-mud process the clay is tempered with only enough water to permit it to flow without rupture. Thus prepared, it is forced through an opening or die of suitable shape and size. The auger machine is a common type; it is a closed cylinder which contains blades for mixing and kneading the moist clay and a tapered screw for forcing it through the die. In making brick the resulting ribbon is cut into the desired length by means of wires. Odd-shaped tile and certain kinds of face brick may be cut by hand. Stiff-mud shaping is employed quite generally for making common brick, face brick, fire brick, and roofing tile and is almost the only method for making hollow tile, sewer pipe, drain tile, and conduit. For sewer pipe, conduit tile, and other large hollow wares, a piston press is used instead of the auger for forcing the clay vertically downward through a die or into a mold. Some articles are shaped from stiff mud by hand.

In dry-pressing (or semidry pressing) the clay is moistened just enough so that the mass will bind together when squeezed in a hydraulic, cam, or screw press. The press may be filled either by hand or from a machine and may be operated by hand or mechanical power. It is the principal process for shaping floor and wall tile and is being taken up by fire brick manufacturers. It may also be used for common brick and face brick, these cheaper grades have likewis been formed first by the soft-mud or the stiff-mud process, partly dried (usually for only a few hours), and then repressed.

Casting is the process in which a finely dispersed mixture of clay suspended in water is poured into plaster molds. As the plaster absorbs water fro the slip a coating forms against the walls of the mold, and when this coating becomes thick enough, the excess slip is poured out. After drying somewhat, the object shrinks away from the mold, which can then be stripped off. A great deal of pottery is produced in this way, and the method is by far the principal one used for shaping sanitary ware.

Drying

All clay products must be dried more or less before they can be fired. Depending upon the climate, the value of the product, and other factors (including such characteristics of the clay as its behavior in shrinking), the drying

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may be conducted in the open, in sheds, or in specially heated rooms or tunnels. In general the ware must not be dried too rapidly at first or it may crack. For expensive, delicate articles elaborate means are often provided for the close control of time, temperature, and humidity. Brick may be dried in the open air or simply under a light roof; occasionally they are placed on racks in open sheds. Probably the majority of modern plants, however, have artificial dryers, usually of the car-tunnel type.

Firing

Various kilns are employed for burning clay products, and common brick are often piled up so as to form their own kiln (scove kiln); arched spaces are left at the bottom for the fire and the outside layers are laid close and plastered with mud to retain the heat. Most kilns are intermittent in operation, but there is a growing tendency to use continuous kilns fired at the middle point, the ware passing from one end to the other on slowly moving trucks.

For ordinary brick a finishing temperature of 1,050° C. is usually sufficient, but for vitrified brick the temperature is higher and has to be continued for a longer period in order that the clay can begin to fuse and thus become dense and hard. According to Dietrich:[32] "Firing temperatures range from 895° C. (1,643° F.) for soft-burned common brick to 1,350° C. (2,462° F.) for hard porcelain and fire brick. A few special products are fired as high as 1,640° C. (2,984° F.)."

The final temperatures must be reached only by easy stages. As a rule the ware as it comes from the drying process still contains 5 per cent or more of moisture which has to be driven off in the kiln. At a somewhat more elevated temperature the combined water and other volatile matter are given off. Often a considerable amount of oxidation takes place, particularly in clays containing much iron or organic matter, and these reactions must be completed before the wares are heated to a temperature much above a red heat. Otherwise the ware may crack, become misshapen, or develop unsightly spots and discolorations.

Glazing

Before applying a glaze or an engobe to delicate ware, the body must be given a preliminary (biscuit) firing. Some highly decorated goods are given several firings. Whenever possible, however, the slip containing the glaze ingredients is applied to the green ware, as this both eliminates the necessity of more than one firing and results in a better bond between the glaze and the body.

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32 - Dietrich, W. F., The Clay Resources and Ceramic Industry of California. Calif. State Min. Bur., Bull. 99, 1928, p. 17.

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DOMESTIC PRODUCTION

Fifteen million tons or more of clay are produced annually in the United States, but since most manufacturers of clay products mine their own clay the quantity of clay sold by producers or mined under royalty in the United States in 1927 amounted to only 3,849,176 short tons, valued at $13,697,159 or $3.56 a ton. The unit value of the clay sold, of course, is much greater than the average for all clay mined, as the marketed production consists principally of the better grades. The clay of largest quantity and value is fire clay. Fire clay also is often made into fire brick and other refractories by the producers themselves, but the bulk of the domestic output of kaolin, ball clay, and other expensive varieties of clay is sold by the producers. Detailed statistics of marketed production, (including in addition to out-and-out sales, clay mined under royalty, and that shipped into another State for fabrication) by States, by kinds of clay, and by uses have been collected for many years by Jefferson Middleton and published by the Bureau of Mines in the annual volumes of Mineral Resources of the United States from which the following average figures have been calculated:

Clay sold by producers in the United States, annual averages for five-year periods, prewar and postwar 1/

Kind	1909-1913		1923-1927	
	Short tons	Value	Short tons	Value
Kaolin.....	132,114	$ 705,352	383,439	$ 3,330,468
Ball clay.....	63,371	231,477	104,333	736,769
Slip clay.....	14,268	25,867	7,312	38,050
Fire clay.....	1,629,097	2,261,738	2,565,583	7,290,872
Stoneware clay....	142,569	143,034	80,076	172,519
Miscellaneous clay	400,546	369,019	653,772	1,078,487
	2,381,965	$3,736,487	3,794,515	$12,647,165

1/ Calculated from annual figures compiled by Jefferson Middleton of the Bureau of Mines.

In order of quantity sold the leading five states in 1927 were Pennsylvania with 23.3 per cent of the total quantity, Missouri with 10.8 per cent, Ohio with 8.4 per cent, New Jersey with 8.1 per cent, and California with 7.5 per cent. Almost one-half of the kaolin comes from Georgia; Florida, Pennsylvania, South Carolina, and a few minor sources furnish the remainder. The outpu of ball clay comes mainly from Tennessee and Kentucky. Fire clay is more widely distributed. For this kind of clay Pennsylvania is by far the leading producing State, but Missouri, Ohio, Colorado, and California are also relatively important. Stoneware clays are mined chiefly near the pottery centers of New Jersey and Ohio and in Illinois.

Statistics showing the sales of clay by uses are necessarily incomplete because many clay miners do not know the purpose to which their clay is put.

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Clay sold by producers in the United States in 1927, by uses, in short tons[1/]

Use	Kaolin	Ball clay	Fire clay	Stoneware clay	Miscellaneous clay	Total
White-bodied ware made from white-burning clays	64,578	60,366	16,764	1,764	- -	143,472
Art pottery	500	423	900	509	272	2,604
High-grade tile	22,790	29,905	18,639	568	3,814	75,716
Chemical stoneware	76	- -	963	7,261	211	8,511
Stoneware	- -	1,078	2,642	74,594	- -	78,314
Enameling	26	708	- -	- -	- -	734
Paper filler	192,307	- -	- -	- -	1,201	193,508
Paper coating	3,510	- -	- -	- -	- -	3,510
Rubber	27,428	- -	2,305	- -	842	30,575
Oilcloth or linoleum	14,511	- -	- -	- -	- -	14,511
Paint filler or extender	12,084	- -	- -	- -	1,250	13,334
Paint pigment	14	331	- -	- -	- -	345
Architectural terra cotta	100	9,538	76,538	12,960	6,480	105,616
Asbestos products	440	579	- -	- -	1,364	2,383
Plaster and plaster products	6,224	- -	11,491	- -	4,075	21,790
Slip for glazing purposes	- -	- -	- -	- -	2/2,478	2,478
Cement	58,594	- -	1,224	- -	- -	59,818
Kalsomine	3,959	- -	- -	- -	- -	3,959
Artificial abrasives	- -	776	3,272	498	3/3,710	8,256
Crayons	500	- -	- -	- -	- -	500
Chemicals	1,500	- -	- -	- -	- -	1,500
Pencil leads	- -	- -	- -	- -	206	206
Saggers	5,304	15,238	144,210	- -	300	165,052
Pins, stilts, and spurs for potters' use	300	- -	6,346	- -	- -	6,646
Wads	- -	- -	33,463	- -	- -	33,463
Gas retorts	- -	- -	378	- -	- -	378
Fire brick and block	26,629	- -	921,440	- -	8,295	956,364
Fire-clay mortar	1,871	426	461,078	- -	- -	463,375
Bauxite and high-alumina brick	- -	- -	10,409	- -	30	10,439
Glasshouse pots	- -	- -	25,184	- -	- -	25,184
Glasshouse supplies, blocks, etc.	295	242	1,365	- -	- -	1,902
Zinc retorts and condensers	- -	- -	79,299	- -	- -	79,299
Clay crucibles	- -	- -	3,140	- -	- -	3,140
Graphite crucibles and stoppers	- -	108	- -	- -	- -	108
Foundries, steel works, etc.	87	- -	442,292	65	39,660	482,104
Unspecified 3/	10,618	45	436,421	136	402,864	850,084
	454,245	119,763	2,699,761	98,355	477,052 4/	3,849,176

1/ Middleton, Jefferson, Clay in 1927. Mineral Resources of the United States, 1927, pt. 2.

2/ Slip clay; except 51 tons of miscellaneous clay used for artificial abrasives.

3/ Includes clay for brick (building and paving), chimney blocks, copper converters, cosmetics; decolorizing oil, flowerpots, flue lining, furnaces, fuses, hollow building tile, modeling, retorts, sewer pipe, shoe and stove polish, soap products, taxidermy, toy marbles, wall paper, and water softener; also black-burning clay.

4/ Includes 6,137 tons of slip clay.

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A much better idea of the magnitude of the clay-working industries is obtained from a study of the production figures for clay products. Previous to 1921 these figures were reported annually by Middleton in Mineral Resources of the United States, but in later years they have been collected each year by the Bureau of the Census, Department of Commerce. Examination of these figures brings out forcibly the extent to which the clay-working industries are dependent upon building construction for their continuance. The manufacture of pottery though representing more than one-quarter of the total value of clay products, requires but a small fraction of the total tonnage of clay annually consumed in the United States. In 1927, the production of pottery was $111,355,441 and of other clay products $295,213,565.

Clay Products Other Than Pottery, and Nonclay Refractories---Production by Class, Quantity, and Value, and Stocks on Hand December 31, 1927, 1926, and 1925.

(Includes data for establishments reporting products valued at less than $5,000)

(Ton, 2,000 pounds; square, 100 square feet)

	Number of establishments	Quantity	Value	Stocks on hand Dec.31
Clay products other than pottery				
Common brick:		Thousands		Thousands
1927	1/ 1,152	1/ 7,002,714	1/ $77,851,145	1/1,541,297
1926	1,223	7,517,211	88,226,625	1,393,508
1925	1,273	7,561,501	88,551,400	1,387,775
Vitrified brick or block:				
For paving---				
1927	79	405,812	9,141,002	109,350
1926	80	381,684	8,918,947	97,021
1925	77	448,492	10,350,093	127,403
Other vitrified brick or block---				
1927	45	97,588	1,622,722	21,191
1926	51	85,896	1,365,794	23,003
1925	41	90,609	1,525,604	21,113
Face brick:				
1927	1/ 452	1/ 2,412,903	1/ 41,520,881	1/ 737,49
1926	456	2,439,820	44,516,236	655,43
1925	421	2,474,690	45,427,625	606,93
Fancy and ornamental brick:				
1927	12	1,456	108,451	44
1926	4	115	3,592	3
1925	9	1,701	50,279	62
Enameled brick:				
1927	7	18,097	1,374,725	10,97
1926	9	15,441	1,275,692	9,46
1925	7	16,931	1,507,659	10,24
Hollow brick:				
1927	44	37,040	436,065	7,73
1926	39	63,359	692,258	7,61
1925	(2)	(2)	(2)	(2)

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Clay Products Other Than Pottery, and Nonclay Refractories---Production by Class, Quantity, and Value, and Stocks on Hand December 31, 1927, 1926, and 1925. (Cont'd.)

(Includes data for establishments reporting products valued at less than $5,000)

(Ton, 2,000 pounds; square, 100 square feet).

	Number of establishments	Quantity	Value	Stocks on hand Dec. 31
Clay products other than pottery---Continued:				
Terra cotta:		Tons		Tons
1927	31	155,932	$16,628,139	28,324
1926	34	155,564	19,666,880	27,073
1925	31	152,441	19,138,690	19,999
Hollow building tile:				
(a) Partition, load-bearing, furring, and book tile--				
1927	1/ 399	1/ 3,605,519	1/ 21,784,658	1/ 769,790
1926	396	3,698,778	23,560,571	660,373
1925	385	3,818,985	25,153,145	704,649
(b) Floor-arch, silo, and corn-crib tile; conduits; radial chimney blocks; fireproofing tile---				
1927	71	508,790	4,714,722	143,794
1926	66	397,639	4,257,857	95,053
1925	54	405,917	4,111,079	99,227
Roofing tile:		Squares		Squares
1927	47	366,764	5,322,248	90,121
1926	44	408,724	7,015,775	114,903
1925	23	289,956	5,155,301	45,023
Floor tile (plain, vitreous, encaustic, quarry, etc.):		Square feet		Square feet
1927	57	20,433,581	4,586,319	4,640,948
1926	65	24,920,354	5,521,965	4,120,140
1925	45	19,243,987	4,361,319	4,360,058
Ceramic mosaic tile (vitreous and semivitreous, unglazed):				
1927	23	20,483,678	4,547,146	5,193,240
1926	19	22,573,178	4,865,967	4,253,988
1925	21	20,331,051	4,092,392	2,933,674
Enameled tile (bright, dull, matt, and semimatt finishes, and glazed ceramic mosaic):				
1927	24	7,083,913	3,356,347	1,484,357
1926	(3)	(3)	(3)	(3)
1925	(3)	(3)	(3)	(3)

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Clay Products Other Than Pottery, and Nonclay Refractories---Production by Class, Quantity, and Value, and Stocks on Hand December 31, 1927, 1926, and 1925. (Cont'd.)

(Includes data for establishments reporting products valued at less than $5,000)

(Ton, 2,000 pounds; square, 100 square feet)

	Number of establishments	Quantity	Value	Stocks on hand Dec. 31.
Clay products other than pottery---Continued:		Square feet		Square feet
Faience tile (including hand-decorated):				
1927	32	3,073,545	$2,419,826	1,097,044
1926	4/ 33	4/ 7,702,558	4/ 4,794,128	4/ 1,482,151
1925	4/ 30	4/ 4,915,525	4/ 3,294,537	4/ 862,515
Wall tile (white, bright-glazed), including trim:				
1927	24	39,537,355	12,503,064	5,286,151
1926	26	39,009,986	12,787,359	2,457,082
1925	22	30,365,838	10,220,260	2,309,769
Draintile:		Tons		Tons
1927	1/324	1/ 734,392	5,511,301	1/ 175,244
1926	301	519,483	3,858,408	184,349
1925	335	660,673	4,960,423	196,945
Sewer pipe:				
1927	107	2,115,688	29,425,913	611,543
1926	111	1,994,333	29,303,094	585,462
1925	104	2,138,672	30,420,828	669,795
Stove lining:				
1927	21	13,646	503,021	5,013
1926	20	11,573	472,904	3,38[illegible]
1925	21	25,852	656,139	5,16[illegible]
Flue lining:				
1927	95	252,019	2,851,526	52,904
1926	89	241,465	2,857,309	47,90[illegible]
1925	63	182,267	2,480,327	31,73[illegible]
Wall coping:				
1927	57	52,841	670,505	10,90[illegible]
1926	54	56,345	685,303	9,75[illegible]
1925	30	37,124	381,367	6,08[illegible]
Fire-clay products:				
(a) Clay brick, block, or tile; boiler and locomotive; other refractory-clay products---		Thousands (9-inch equivalent)		Thousand (9-inch equivalent)
1927	1/ 212	1/ 863,205	1/34,138,408	1/ 223,58[illegible]
1926	230	1,007,784	40,013,394	253,89[illegible]
1925	238	990,113	40,727,578	221,88[illegible]

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Clay Products Other Than Pottery, and Nonclay Refractories---Production by Class, Quantity, and Value, and Stocks on Hand December 31, 1927, 1926, and 1925. (Cont'd.)

(Includes data for establishments reporting products valued at less than $5,000)

(Ton, 2,000 pounds; square, 100 square feet)

	Number of establishments	Quantity	Value	Stocks on hand Dec. 31.
[redacted]roducts other than pottery---Continued:		Thousands (9-inch equivalent)		Thousands (9-inch equivalent)
(b) High-alumina brick (over 40% Al_2O_3)---		Thousands		
1927	13	11,351	1,187,096	5,537
1926	14	9,095	978,624	3,277
1925	10	4,966	436,123	2,510
(c) Special shapes---		Tons		Tons
1927	37	132,523	2,696,981	41,149
1926	40	61,909	1,714,914	17,010
1925	(2)	(2)	(2)	- -
Glass-house tank blocks, smelting pots, stoppers, floaters, and rings:				
1927	14	41,147	2,310,473	23,647
1926	(2)	(2)	(2)	- -
1925	(2)	(2)	(2)	- -
Chimney pipe and tops:				
1927	28	7,905	243,034	2,510
1926	(2)	(2)	(2)	- -
1925	(2)	(2)	(2)	- -
Segment blocks:				
1927	14	58,989	967,422	36,316
1926	(2)	(2)	(2)	- -
1925	(2)	(2)	(2)	- -
Refractory cement (clay):				
1927	40	45,609	1,241,257	(5)
1926	42	31,816	1,328,216	(5)
1925	(6)	(6)	(6)	- -
Clay sold, raw or prepared:				
1927	239	482,311	2,497,979	(5)
1926	250	476,020	2,666,843	(5)
1925	240	656,918	3,482,236	(5)
Clay products not elsewhere classified:				
1927	65	- -	3,051,189	(5)
1926	94	- -	6,581,590	(5)
1925	118	- -	8,426,249	(5)

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Clay Products Other Than Pottery, and Nonclay Refractories---Production by Class, Quantity, and Value, and Stocks on Hand December 31, 1927, 1926, and 1925. (Cont'd.)

(Includes data for establishments reporting products valued at less than $5,000)

(Ton, 2,000 pounds; square, 100 square feet)

	Number of establishments	Quantity	Value	Stocks on hand Dec. 31.
Clay products other than pottery---Continued:				
Nonclay refractories		Thousands		Thousands
Silica brick:				
1927	27	245,881	$12,756,994	56,876
1926	31	266,409	13,614,033	51,114
1925	28	235,877	11,280,127	(5)
Magnesite and chrome brick:				
Magnesite brick---				
1927	6	.....	.....	--
1926	7	.....	.....	--
1925	7	13,941	3,874,176	3,642
Chrome brick---		16,130	4,762,645	2,945
1927	4	12,732	3,751,872	(5)
1926	4			
1925	4			
Refractory cement(magnesite, etc.):		Tons		Tons
1927	21	59,508	1,184,121	(5)
1926	17	45,788	1,045,468	(5)
1925	7/ 38	7/ 78,477	7/2,270,276	(5)
Other refractories, including silicon-carbide and bauxite brick:				
1927	17	--	1/5,430,387	(5)
1926	18	--	5,083,373	(5)
1925	16	--	3,062,156	(5)

1/ Preliminary figures previously issued have been revised.
2/ Not reported separately; included in "Clay products, not elsewhere classified."
3/ Not reported separately; included in "Faience tile."
4/ Includes data for "Enameled tile (including bright, dull matt, and semimatt finishes, and glazed ceramic mosaic)."
5/ No data for stocks on hand.
6/ Not reported separately; included in "Refractory cement (magnesite, etc.)"
7/ Includes "Refractory cement (clay)."

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IMPORTS OF CLAY AND CLAY PRODUCTS

As regards tonnage the imports of clay have always been relatively small, but since they have consisted of special kinds of clay, mostly high in price, they have been extremely significant. The whiteware, porcelain, sanitary ware, paper, paint and oilcloth industries formerly relied principally upon kaolin or china clay imported from Cornwall, England. Prior to 1914 comparatively large and increasing quantities of high-grade plastic fire clay were imported from Germany for use in the manufacture of crucibles, glass pots, abrasives, pencil leads, and enameled ware. A little English clay was also employed for these purposes, and the ball clay used by American potters was very largely of English origin.

The effect of the war was to eliminate German clays and to curtail drastically the importation of supplies from Great Britain. After the war prices remained high and the situation with respect to ocean shipping acted as a further deterrent to the resumption of deliveries from overseas. Nevertheless in 1920 imports far exceeded those of prewar years, and subsequently the use of foreign clays has continued on a high level. The one exception to this statement is the imports of "common blue and the Gross Almerode glass pot clay" which have declined, averaging in recent years scarcely one-third the prewar amount. The imports under this designation have consisted almost exclusively of refractory clays free from impurities that would color a glass-mix. When the necessity arose deposits were opened up in the United States and subsequently domestic clays of similar character have been successfully substituted for the German clays by most glassmakers and also to a certain extent by the manufacturers of crucibles, pencils, enamelware, and abrasives for which this class of clay was likewise employed. The use of foreign ball clays has also fallen off.

Kaolin now forms an even greater percentage of the total clay imported, constituting 86 per cent of the total in 1927. This clay has always been obtained almost wholly from Cornwall where are found the largest known deposits of white clays. Roughly one-half the exports of Cornish clays are shipped to the United States. The "best" West-of-England china clays have a reputation for quality superior to that of clays found elsewhere in the world, except possibly in Bohemia. They have been carefully prepared and the different brands have been kept remarkably uniform year after year. Even the inferior qualities of English clay have been carefully graded and almost invariably have maintained a uniform standard. Great Britain also furnished by far the bulk of the imports of clays other than kaolin. The average value of such clays imported from Great Britain is much higher than that of clays imported from other countries - with the exception of Germany, which still furnishes chiefly high-grade clays used for glass refractories, though in reduced quantities. In recent years fairly substantial imports (16,300 short tons in 1926) of clay have been imported from Yugoslavia and Albania, but the value per ton has been less than one-quarter that of English or German clays.

The following table shows that the imports of clay, particularly those of kaolin, are much larger now than they were before the war. It should be noted, however, that they have not increased to the same extent as domestic

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Clay imported for consumption in the United States, prewar and 1919-1927. 1/

Year	Kaolin or china clay			Common blue and Gross Almerode glass pot clay		All other clays				Total	
		Value				Unwrought		Wrought 2/			
	Short tons	Total	Average	Short tons	Value	Short tons	Value	Short tons	Value	Short tons	Value
Prewar 3/	261,266	$1,562,683	$5.95	19,763	$159,788	31,836	$126,313	1,423	$24,312	314,288	$1,873,096
1919	180,592	1,965,393	10.88	4	133	23,759	187,550	498	4,262	204,853	2,157,338
1920	361,800	3,568,677	9.86	6,837	157,201	34,252	272,524	691	10,267	403,580	4,008,669
1921	162,906	1,546,285	9.49	4,468	77,217	41,421	348,870	120	2,313	208,915	1,974,685
1922	310,136	2,963,420	9.56	7,323	84,415	40,624	327,388	2,566	29,398	360,649	3,404,621
1923	311,298	3,046,191	9.79	12,999	121,272	65,379	481,614	1,676	21,892	391,352	3,670,969
1924	353,124	3,188,454	9.03	7,059	62,883	82,562	706,018	1,322	18,685	444,067	3,976,040
1925	372,552	3,195,694	8.58	11,889	107,940	49,991	499,325	2,383	29,266	436,815	3,832,225
1926	396,219	3,484,054	8.79	6,608	60,391	84,512	672,223	2,331	31,243	489,670	4,247,911
1927	339,014	2,937,113	8.66	3,884	39,451	50,017	447,888	1,585	24,518	394,500	3,448,970
1928	307,303	2,962,269	9.64	10,256	90,742	51,163	429,788	1,653	23,564	370,375	3,506,363

1/ Figures compiled by J. A. Dorsey, of the Bureau of Mines, from records of the Bureau of Foreign and Domestic Commerce.

2/ Includes washed or manufactured clays.

3/ Five-year averages, 1909-1913.

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production, which (as has already been shown) has increased enormously, kaolin in particular having advanced from only 125,000 or 150,000 short tons before the war to 454,245 short tons in 1927.

Studies made from time to time by the United States Tariff Commission have indicated that much of the unwrought clay under the basket classification consists of ball clay, whereas the imports described as "Wrought" include pencil and modeling clays.

During the five-year period, 1909-1913, immediately preceding the outbreak of the Great War, the values of the annual imports of pottery averaged approximately $10,000,000 and those of brick, fire brick, tile, etc., a little under $225,000. The leading items were china and porcelain (more particularly decorated ware), the American market for which was supplied mainly by imports from Germany, England, France, Japan, and Austria-Hungary (Bohemia). The imports of bulky products were confined to occasional shipments in ballast or deliveries from Canadian plants just over the border. Quarry tiles and a few other products of relatively low unit value, however, were imported because of special quality or pleasing color.

The present situation with respect to pottery is not greatly different than it was before the war. As regards table ware, $10,000,000 to $12,000,000 worth of china and porcelain and $5,000,000 to $7,000,000 worth of earthenware are annually imported. While these values are higher than the former averages this fact probably does not indicate any increase in the volume of pottery imported, because prices have increased considerably. In the import trade of tile, however, there has been a marked change, imports in recent years amounting annually to more than $1,000,000 in value or several times pre-war. Here again, however, the imports consist chiefly of high-grade ware, mainly glazed wall tile such as are used in bathrooms and more recently including also vitrified floor tile in greens, blues and blacks. Color is in demand in modern homes and the German colors have proved popular and have been available at competitive prices. An even more marked change has developed in the imports of brick. Formerly, except for a small over-the-border trade with Canada, the American market for structural brick was practically self-contained, imports in particular being almost nil. In 1926 and again in 1927, on the other hand, the imports of bricks amounted to approximately 94,000 thousand, having a value in the former year of $770,055. To a large extent these imports now come from Belgium and the Netherlands. Shipments from both of these countries consist of common brick, but the Dutch brick, because of their color, appeal to some architects and are actually used in many cases as face brick.

TARIFF DUTIES

The tariff act of 1922 imposes the following duties (par. 207):

China clay or kaolin, $2.50 per long ton; fuller's earth, unwrought and unmanufactured, $1.50 per long ton; fuller's earth, wrought or manufactured, $3.25 per long ton; bauxite, $1.00 per long ton; clays or earth, unwrought or

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unmanufactured, including common blue clay and Gross-Almerode glass pot clay, not specially provided for, $1.00 per ton; wrought or manufactured, not specially provided for, $2.00 per ton.

Based upon the average value at the foreign port in 1927, these duties were equivalent to approximately 29 per cent in the case of kaolin imports, 10 per cent on glass pot clays, 9 per cent on other crude clays, and 8 per cent on unspecified wrought clays (washed or manufactured).

Pottery and most other clay products are dutiable under the same act. The average duties collected on all imports of pottery recently have been somewhat more than 60 per cent, the duties on decorated china and porcelain being 70 per cent. The average duty collected for other dutiable clay products (consisting in large part of decorative tile) has been recently approximately 40 per cent. Brick are mostly free of duty, though under paragraph 1536 a countervailing duty is provided on imports from countries which levy duties on American brick. The amount of duty in such case is equal to that charged upon imports of brick into those countries from the United States. Duties have been levied upon imports of brick from Canada, Mexico, and Germany.

With respect to common blue or Gross-Almerode clays the act of 1922 represents a departure from the custom of previous acts. The act of 1883 and subsequent acts, including the Underwood Act of 1913, specifically provided for its free entrance, apparently on the assumption that satisfactory substitutes could not be found in this country. China clay, on the other hand, was specifically mentioned in the dutiable lists of the act of 1883 and in all subsequent acts. The rate was $3 per long ton in the acts of 1883 and 1890, $2 per ton in the act of 1894, and $2.50 (the present rate) in the acts of 1897 and 1907, and $1.25 in the act of 1913. Miscellaneous clays have been dutiable for many years. On unwrought or crude clay the duty of $1.50 per ton in the acts of 1883 and 1890 was progressively reduced to $1 in 1894 and 50 cents in 1913 but was increased back to $1 in 1922. The duty on wrought clay has generally been double that on crude.

EXPORTS OF CLAY AND CLAY PRODUCTS

Kaolin obtained from Southern Appalachian mines was at one time sold by the Indians to English traders and used in the manufacture of English porcelain[33] but for many decades little or no domestic kaolin is known to have been exported while great quantities of English kaolin have been imported into this country. American fire clays on the other hand have been exported to Canada, Europe, and South America. Though representing only a small proportion of the tremendous quantities of such clays produced in this country for home consumption, the exports of fire clay, statistics for which have been available since 1915, have amounted to a substantial tonnage, ranging in recent years from 40,000 to 50,000 short tons annually and being valued usually at more than $7 per ton at port of shipment. Domestic clays of this class are of good quality, and the deposits are situated close to the Atlantic seaboard.

33 - Watts, A. S., Mining and Treatment of Feldspar and Kaolin in Southern Appalachian Region. Bull. 53, Bureau of Mines, 1913, pp. 9-10.

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Statistics of exports of clays other than fire clay have been published since 1915, but they are to a certain extent misleading for the reason that they include fullers' earth and other earthy products in addition to clays. In 1922 a little kaolin (2,091 short tons) was listed separately, and in other years some domestic paper and pipe clays were exported to Canada. Other miscellaneous refined clays of domestic origin find a considerable foreign market, being shipped not only to Canada, Mexico, and Cuba but also to various European countries. Almost one-third of the total value of these "other clays" exported in 1926 was credited to Pacific coast ports, and the unit value of the exports from such ports was well over $30 per short ton. The average value of all exports was about $50 per ton, indicating a highly refined product such as prepared clays for use in decolorizing mineral and other oils. Among the manufactured products exported, the principal items are refractories, electrical porcelain, and earthenware plumbing fixtures, but also there is exported a substantial amount of crockery and other earthenware and a very small amount of china and porcelain ware, wall and floor tiles, and structural brick and hollow tile.

MARKETS AND PRICES

The markets for clay are mainly contractual. Fairly definite price figures can be obtained for certain kinds of china clays and ball clays, particularly the well-known English brands and a few American brands that have a relatively wide market, but for other clays, notably the cheaper clays, the price is governed by agreements between producers and consumers. As regards the bulk of the output, the clay is not sold as clay, and hence there is no price of record, the value of the clay being the cost of mining and haulage to the brick machine or mixer. Since this cost is often as low as 15 cents and seldom more than 25 cents per ton, it is evident that the opportunities for independent miners to sell clay to existing brickyards are extremely rare. Except for some special variety that may be desired for mixing purposes, the cartage alone ordinarily would exceed the delivered value, leaving no allowance for mining costs or profit. Common brick clays and clays suitable for making certain other heavy products are found in every State, and if suitable clay beds are not available in a certain locality it is usually more economical to transport the finished product from the nearest existing plant rather than to build a plant locally and transport the raw clay. Even fire clays as a class must be sold close to the point of origin.

The best available data as to the prices obtainable for the various kinds of domestic clays are provided by the annual reports of producers to the Bureau of Mines relative to the total tonnage and value of sales. The value at the mine of clays of similar quality will vary, of course, according to the distance from market. The variations due to differences in freight rates as well as those due to differences in quality of the clays themselves are reflected in the tables presented annually by Middleton in Mineral Resources of the United States, Part II; these show the tonnage and value of clay sold by producers in the United States, by States and kinds. Average figures for all States are shown in the following table:

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Total sales and average values per short ton of various kinds of clay sold by producers in the United States, pre-War and 1919-1927. 1/

	Total quantities sold, short tons	Kaolin and paper clay	Slip clay	Ball clay	Fire clay	Stone-ware clay	Brick clay	Miscel-laneous clay	All classes
Prewar 2/	2,381,965	3/$5.35	$1.81	$3.65	$1.38	$1.00	$ .82	$1.00	$1.43
1919	2,275,100	9.67	3.41	8.00	2.64	1.33	(4)	1.55	3.12
1920	3,116,212	10.68	4.61	8.41	3.17	2.16	(4)	1.45	3.73
1921	1,716,746	9.70	3.22	6.56	2.98	2.13	(4)	1.48	3.51
1922	2,647,700	8.51	4.79	5.74	2.76	1.90	(4)	1.38	3.15
1923	3,434,660	8.69	5.12	6.40	2.86	2.39	(4)	1.36	3.26
1924	3,691,119	8.95	5.25	7.01	2.76	1.98	(4)	1.44	3.12
1925	4,030,420	8.77	5.09	6.38	2.85	2.09	(4)	1.44	3.16
1926	3,967,198	8.73	5.32	7.73	2.88	2.21	(4)	2.18	3.56
1927	3,849,176	8.40	5.27	7.63	2.86	2.07	(4)	2.16	3.56

1/ Compiled from data furnished by Jefferson Middleton, Bureau of Mines.
2/ Five-year averages, 1909-1913.
3/ Average price of kaolin $7.93, and of paper clay $3.56 per short ton.
4/ Included under "Miscellaneous clay."

It is possible to calculate the unit values of imported clays as shown by the import statistics. The foreign values as reported relate to the value at the port of shipment and do not include freight and certain other charges. As regards most of the import classifications, however, the average value is of no particular significance for the reason that so many different kinds of clay are likely to be included under the same import designation. Only in the case of china clay do the import statistics afford even a rough index of the trend of prices over a period of years. For imports of this class the relative proportions of high-grade and low-grade clays do not vary markedly from year to year, although even in this class, comparisons of present-day averages with pre-war figures may be misleading because a much larger proportion of the American market for low-grade clays is now supplied from domestic sources. Actually the prices of English china clays during the last few years have been little different than they were previous to 1914. Delivered ex-ship at United States Atlantic ports, English clays suitable for pottery use may be quoted at an average price of approximately $20 per ton, including ocean freight which amounts to approximately $3.50 per short ton (14 to 15 s.). The prices (for English lump) quoted in the trade journals are from $12 to $21, the range representing differences in quality. As a general rule it may be said that domestic clays have to meet these prices for English clays. Florida clays, for example, were being sold f.o.b. mine in 1928 at $13.50. After adding the freight amounting to $8 or $9 to consuming market this places them upon a competitive footing with English clays, the quotations for which do not include duty or the freight from the port of entry to consumer's plant. For paper clays there is a fairly definite dividing line based upon relative costs of transportation. Manufacturers north of this line, which runs somewhere between Philadelphia and New York, mainly use English clays, while those closer to domestic mines in the southern States mainly use American clays.

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There has been a marked improvement in the character of American kaolins. The Bureau of Mines and the Bureau of Standards as well as other Federal and State agencies have cooperated with the miners in devising better methods of beneficiation and with the potters in working out methods of utilization. Uniform clays are now produced regularly by a number of American mining companies. While it has been demonstrated that American clay as a rule can not be substituted pound for pound for English clay in a pottery batch mixture, satisfactory results are now obtained by using proper blends of American clays. The situation is well set forth in the following extract from an editorial that appeared in The China Clay Trade Review section of the Chemical Age (London) under date of July 21, 1928:

> "* * * the fact has to be faced that nowadays, in consequence of the strides made in the production of American domestic clays, it is not easy to induce buyers to use British china clays in preference to the domestic article in certain markets, particularly those within a reasonable distance of the areas of production, and especially as regards the cheaper grades."

In order further to improve its product, at least one domestic mining company is giving some of its clay a special chemical treatment or bleach, thereby making it suitable for coating as well as filling high-grade paper.

The market prices for clay products vary widely in different parts of the country, depending upon local supply and demand. On May 1, 1928, for example common brick delivered on the job was priced at $26 per thousand in Holyoke, Mass., and at only $12 in Chicago and $12.50 in Los Angeles and Terre Haute. Similarly, hollow clay tile (8 x 12 x 12 in.) was sold on the same date in Cleveland at 13 cents and in Trenton at 26 cents each. Prices of front brick are largely influenced by the fashion prevailing at the moment. In the New York market during 1928 gray colors proved most popular and hence commanded the best prices. Whereas the best Hudson River common brick delivered on the job was worth only $17 to $18.50 rough grays fetched $36 to $43; smooth grays $36 to $45; rough buff selection $33 to $38.50; smooth buffs $36 to $42; rough reds $30 to $36; smooth reds $33 to $39; Colonials $29.50 to $42.50; and Court $30 to $34.

The decorative possibilities of brick as well as of other clay products have only begun to be appreciated by the public, but already the demand for artistic effects has had a profound effect upon the industry. Formerly brick almost never went as far as 100 miles from the yard in which it was made, but recently shipments have been made all the way across the continent. In one case, at least, the freight and drayage amounted to almost double the price of the brick. This illustration, of course, represents an extreme case, but it serves nevertheless to emphasize the fact that people are more and more willing to pay the price in order to obtain brick of pleasing color or of a shade that harmonizes with the popular taste or the fancy of the moment.

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ROYALTIES[34]

Shales and surface clays are commonly valued in the bank by appraisal companies on the basis of 5 cents per ton, occasionally higher. Royalties are sometimes figures as high as 25 cents per thousand brick, which is equivalent to 8 or 10 cents per ton for the raw clay. For fire clay they range from 6 to 50 cents per ton, the latter price having been forced, for example, upon an existing plant that after exhausting its own deposits would otherwise have had to pay heavy freight on far more distant material. For No. 2 fire clays (suitable for ordinary fireproofing, face brick, sewer pipe, and moderate duty fire clay products) the usual royalty is 10 cents per ton. In general, typical royalties will be as follows: Shales and common clays 5 cents per ton; moderate-duty fire clay 10 cents per ton, and high-grade fire clays 10 to 25 cents per ton.

ECONOMIC CONSIDERATION

Quick profits are not to be found in clay mining. With the possible exception of a fortunate discovery of a high-grade kaolin deposit, no profits at all can be made until an expensive plant has been built, and this can not be done wisely before a great deal of time and money has been spent on careful studies of the deposit and preliminary surveys of potential markets. In some respects the production of clay is less speculative than metal mining, but such increase as there may be in the safety of capital invested in a well-planned operation of this sort is accompanied by an almost complete absence of opportunity for good luck. The maximum as well as the minimum yield of a clay deposit can ordinarily be determined fairly accurately beforehand. It is possible to know the extent and nature of the clay, and if the preliminary diagnosis is incorrect the result inevitably will be disastrous. A clay-working plant must be adapted to the material which it is intended to work and to the available labor supply. If the nature of the clay changes, the existing equipment may have to be scrapped and new machinery installed. When the workable clay nearby becomes exhausted, the plant is worthless whether it is worn out or not; almost never can it be removed to a new location successfully.

Except for ware made from the finest grades of clay the location of clay-products factories is determined by the presence of raw materials. Suitable clays for making most of the bulk products are to be found in all the States and usually in different parts of each State. The market for common brick and tile, therefore, must be close at hand; otherwise the freight rate of market will prevent successful competition with more favorably situated establishments. A deposit of poor clay near the market is usually more valuable tha a deposit of good clay further away. Fire brick, sewer pipe, pressed brick, and stoneware can often be shipped fairly long distances because they command higher prices than common brick and also because the requisite raw materials

34 - The data under this head were presented by Carey P. Ellis in The Clay Worker, June, 1928, p. 567.

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are not so widely distributed. Common brick can be sold in distant markets only when the color is exceptionally pleasing and popular. Factories producing whiteware and wall tile, products that are made from mixtures of raw materials drawn from widely separated sources, are located where shipping facilities are good and fuel and labor easily obtainable. Clays used for making the better grades of pottery and clay products may be sold to the manufacturers of these products, but for most classes of clay wares the clay miner has to work up his material into a finished product before he can sell it.

Occasionally it may be necessary to look for a clay deposit, but ordinarily the problem is to find the market. In growing communities, even in most of our largest cities, clay banks containing material suitable for the manufacture of ordinary structural ware lie idle awaiting the investor. They may have been exposed in stream banks or gullies or they may have been discovered in quarries, wells, or railway or highway cuts. Usually, however, before they can be exploited commercially, their nature and extent must be carefully determined. After preliminary tests have indicated that the clay actually is suitable for certain purposes the next step is to determine accurately the size, extent, and degree of uniformity of the deposit. Successful companies often adopt the policy of prospecting their deposits by means of drill holes spaced systematically on the corners of 100-foot squares, taking separate samples at every 2 feet. In the case of extremely thick clay or where the beds are irregular in thickness or character the spacing of the holes may be 50 feet apart or even less. In addition to the holes a few trenches and one or more test pits ought usually to be dug. The individual samples are tested separately and the results are interpreted with a view to possible blending of the clay from different portions of the deposit as well as to ascertain what sort of mixtures are likely to be made if two or more beds and perhaps the overburden were all mined together.

Too much attention can scarcely be given at this stage of the development to the nature and working properties of the clay. Experience is the only safe guide, and the behavior of the clay must be studied with great care by competent persons and on the basis of samples which truly represent material that can be mined economically, year after year, without substantial change in quality. A practical burning test may even lead to unwarranted conclusions. The effect of volatile matter given off in burning, for example, may not be revealed when only a small trial piece is placed in a kiln filled with other articles. Always, moreover, it should be remembered that, before spending even $25 or $50 for a laboratory test on a sample of clay, one should make certain that the sample truly represents a quantity of clay that, when mixed commerciall will have the properties of the sample itself.

Particular stress should be laid upon the fact that clay mining is a long-time proposition. Staley,[35] for example, calls attention to the desirability of purchasing adjoining land (if clay-bearing) at the start in order to

35 - Staley, Homer F., Practical Handling of Iowa Clays: Iowa State College of Agriculture and Mechanic Arts, Eng. Exp. Sta. Bull. 43, 1916, 48 pp.

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guarantee future supplies, because later, when the need for such supplies arises, the price of the land will doubtless be much higher. He also emphasizes the importance of cheap digging. Since even a small plant will consume one or two million tons in the course of its life, a considerable increase in initial investment is warranted if, as often happens, hand-digging costs 15 cents and machine-digging only 5 cents per ton. He has listed the following information which should be obtained by the examining engineer during the early stages of his investigation:

1. Amount of clay of suitable quality present.
   (a) Average depth of layer of suitable quality.
   (b) Extent of the layer.
   (c) Weight per cubic foot.
2. Method and cost of digging the clay.
   (a) Physical character and depth of clay or clays.
   (b) Amount of character of overburden.
   (c) Amount and character of layers or nodules of waste.
   (d) Drainage.
3. Most economical site for plant with respect to
   (a) Delivery of material from pit, and from
   (b) Railroad spurs.
4. Kinds of ware that can be made and type of machinery, dryer and kilns to be used.
   (a) Physical and burning properties of the clay.

In addition to the physical nature of the clay deposit and the technica problems connected with its exploitation, there are important practical busines considerations to be faced. In addition to clay, fuel is required in large quantities. Formerly as much as 1 ton of coal was required to fire a thousand bricks. Many modern brick plants now require scarcely half this amount, but nevertheless the cost and suitability of fuel available is a factor of consider able significance. The labor market also has to be considered, but the outstanding purely economic considerations relate to (1) capital considerations and (2) market conditions. Under capital charges consideration must be given to the cost of land, capital required to build the plant, and working capital to finance early operations and to provide for contingencies, rent, interest, taxes, and so on. Under market considerations the determining factor is the probable demand for the product at any price above actual cost of production; but this demand must be examined with respect to probable competition from other sources and the cost of production, selling, and transportation. That each plant must be considered as a separate problem is indicated by the follow ing cost sheets in a pamphlet published recently (1928) by the Common Brick Manufacturers' Association of America:

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COST OF COMMON BRICK AS REPORTED BY OPERATING YARDS

Manufacturers	X	Y	Z
Brick made this month	2,325 M	1,072 M	3,123 M
Mining	.65	.63	.22
Transporting	- -	- -	.36
Machining	2.30	1.65	1.24
Drying	- -	.14	.75
Total Making	2.95	2.42	2.57
Setting	1.02	1.34	.90
Burning	2.50	3.79	2.58
Cost at kiln	6.47	7.55	6.05
Drawing	- -	- -	- -
Yard overhead	1.77	6.65	1.62
Cost at yard	8.24	14.20	7.67
Administrative	1.34	2.72	2.34
Inventory cost	9.58	16.92	10.01
Loading	.77	.99	2.07
Selling	.97	.26	.71
Total cost per M	11.32	18.17	12.79
Sales price at yard	15.92	16.50	15.50
Average profit per M	4.60	- -	2.71
Average loss per M	- -	1.67	- -

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The Census reports separately certain data for establishments engaged primarily in the manufacture of a single class of products. These data with respect to the year 1925 may be rearranged to yield the following information:

Product	Averages per wage earner 1/ employed				Percentage of total value represented by		
	Horse power	Wages per year	Value added by manufacture	Total 2/ value of products	Wages 3/	Materials 4/	Overhead and profit
Common brick	5.90	$1,230	$2,130	$2,960	42.1	27.8	30.1
Face brick	5.60	1,245	2,290	3,260	38.2	30.3	31.5
Architectural terra cotta	1.50	1,500	3,020	3,680	40.8	17.9	41.3
Hollow building tile	6.80	1,280	2,410	3,450	37.3	30.1	32.6
Roofing tile	4.52	1,450	3,490	4,490	32.2	22.4	45.4
Floor, ceramic, mosaic, faience, wall tile,	1.55	1,140	2,030	2,920	39.1	30.3	30.6
Vitrified brick, etc.	7.04	1,180	2,120	3,230	36.4	34.0	29.6
Drain tile	8.87	990	1,850	2,670	37.2	30.7	32.1
Sewer pipe	3.56	1,270	2,230	3,130	40.7	28.8	30.5
Fire brick	4.04	1,160	2,220	3,340	34.9	33.7	31.4
Red earthenware	2.90	1,210	2,570	3,400	35.6	24.7	39.7
Stoneware, etc. 5/	2.25	1,100	2,080	2,950	37.6	29.7	32.7
Whiteware	7.36	1,160	1,700	2,450	47.4	30.4	22.2
Hotel china	1.46	1,280	2,130	2,690	47.5	20.7	31.8
China plumbingfixt.	1.80	1,580	2,470	4,000	39.4	38.3	22.3
Electrical porcelain	1.87	1,230	2,330	3,320	39.4	26.6	34.0

1/ Based on average number employed.
2/ Total value less cost of materials.
3/ Includes amounts paid for contract work.
4/ Including also cost of fuel, electric power, and mill supplies.
5/ Includes yellow and Rockingham ware but not chemical stoneware.

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That wages form a leading factor in the cost sheets is apparent from the foregoing figures, but the actual percentage is far greater than these figures show for the reason that under "Materials" the Bureau of the Census includes the cost of mining the clay and transporting it to the plant, a large part of which, of course, is labor.

CONCLUSIONS

In the preceding pages mention has been made in several places of the fact that the value of a clay deposit is created by the market. A certain amount of descriptive matter has been presented and some information given as to the adaptability of different clays for specific purposes. A few warnings have been given with respect to various pitfalls in the way of practical operating. It is hoped that many of the suggestions made not only will contribute to a bird's eye view of the clay industries but will prove specifically helpful to those that contemplate entering such industries and even to those already engaged therein. It would be impossible, however, to include within a reasonable number of papges a complete recital of all the factors that ought to be considered in connection with a prospective clay-mining enterprise. Even if it were possible to do so, it would still be necessary to include the statement that the application of well-known factors to a specific enterprise calls for wide practical experience as well as judgment.

Two points in particular need to be stressed. The first relates to market. With negligible exceptions no deposit can be considered of immediate economic worth unless it is within easy reach of a populous territory which will readily absorb the output. Ordinary clay situated far from the railroad or even on a railroad but many miles distant from consuming centers is virtually worthless.

The second point is that the manufacture of clay products is no business for the amateur. The requisite plant costs too much and the risks of adopting the wrong process or of attempting to make a certain product from the wrong kind of clay are far too great for one to take unnecessary chances. Brickmaking and many other clay-product manufacturing processes appear to be quite simple, and it is true that, once started, they often are conducted with commercial success by rule-of-thumb methods. Nevertheless, all over the country there are idle plants standing as mute monuments to the departed hopes of investors who believed that the exploitation of clay deposits could be safely undertaken without first securing the disinterested professional advice of widely experienced and wholly competent persons. Almost as deplorable are the many plants that, though they manage somehow to keep going, fail to realize the full opportunities inherently afforded by the enterprise. These partial failures may be due to careless sampling, lack of understanding of the size and nature of the deposit, or to inexpert planning generally. All phases of the situation must be analyzed and properly coordinated. It is not enough to carry out the field examination properly, to conduct exhaustive laboratory tests, or to make a complete market analysis of the prospective sales territory; all three of these lines of investigation must be properly coordinated and then a suitable plant must be built. Finally, after covering the cost of the plant

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sufficient additional capital must be provided to finance the early stages of operation. Even the best-planned enterprise is beset with numerous difficulties while its labor force is being trained and while its operating routine is being perfected. Sales resistance likewise is usually at a maximum when the untried product of a new plant is being introduced.

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